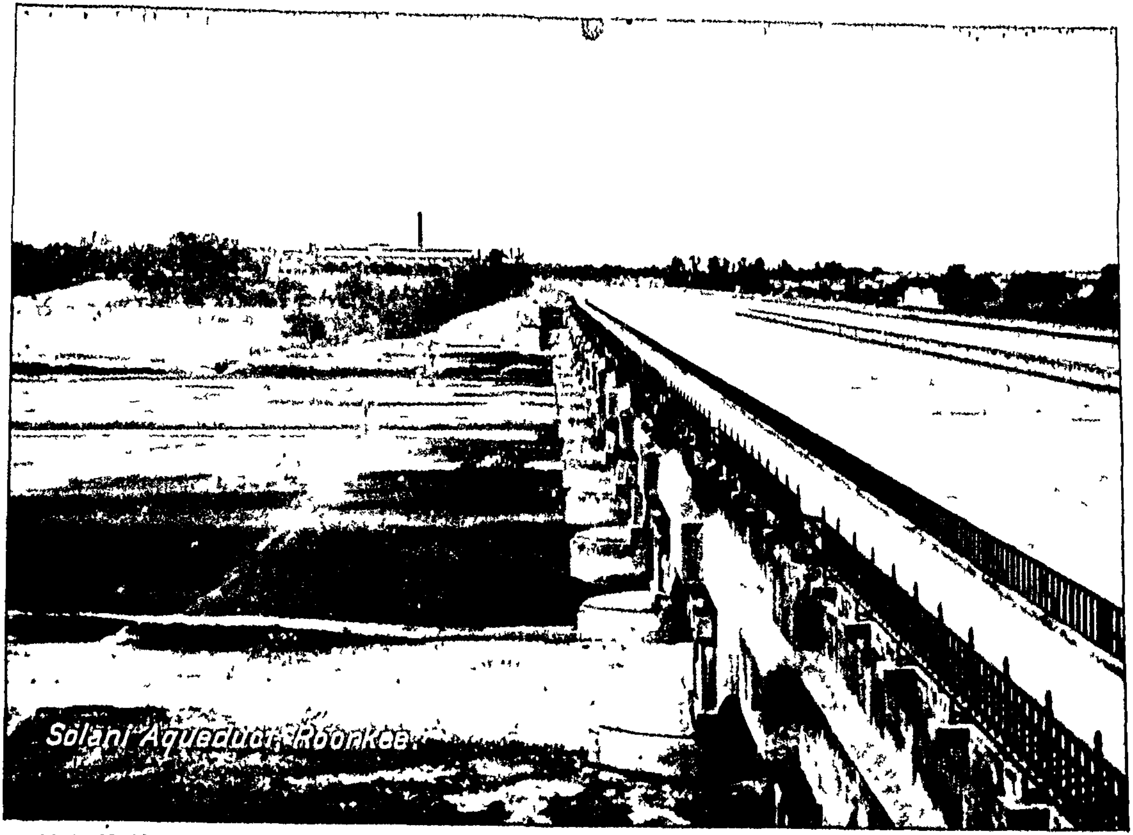

Photo.-Mechl. Dept., Thomason College, Roorkee.

SOLANI AQUEDUCT, GANGES CANAL.

ROORKEE TREATISE ON CIVIL ENGINEERING.

IRRIGATION WORK

IN INDIA.

VOLUME I.

BY

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ROORKEE

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PREFACE TO ROORKEE TREATISE

The latest edition of the text book of Irrigation Works for the Thomason College compiled by the late Colonel Medley R E, was issued in 1873 The advances since made in the knowledge of irrigation detail generally and in the science of equitable distribution in particular have for some considerable time called urgently for a work on the subject dealing with the principles on which a sound and satisfactory enterprise can be projected and constructed with that certainty of result which is so necessary for the prosperity of the agricultural classes and the safety of the capital invested

The greater part of the matter now published consists of notes made by the author when an Executive Engineer in the Irrigation and Agricultural Department United Provinces engaged on construction and remodelling works investigations into well irrigation, and on the projects for the Sardah Canal and the Cawnpore Extension of the Ganges Canal

Extracts from other sources have been acknowledged in the text but as far as possible long descriptions of existing works have been omitted and the matter confined to general leading principles

The author trusts this work may be found practically useful by the younger members of that Irrigation Department to which for 20 years he was proud to belong as well as by the Students for whom it is more particularly intended, and he will be greatly obliged to any readers who may point out any errors that may have been overlooked or for suggestions as to any additions that would tend to extend the usefulness of the work

ROORKEE

J C

5th July 1901

Preface to the Revised Edition of the Roorkee Treatise on Irrigation Works

Colonel Clibborn's Treatise on Irrigation works has, by many, been considered too discursive On being asked to revise it I was at the same time requested to remove this defect.

The treatise, as it stands is a most excellent reference book for Canal or Agricultural Engineers working in Northern India There is very little in it that may be considered as out of date, and a great deal of the information is at first hand and of an exceedingly useful description for the Canal Engineer

For students, not intending to join the Irrigation department of the Public Works department it is undoubtedly far more discursive than it need be However the Professor of Civil Engineering lecturing on Irrigation works, need not be so discursive, but he will certainly find the text book a very great help

For those students who on passing out of college, join the Irrigation department, it will be a distinct advantage to have in their College text book, an efficient book of reference

Considering *their* needs as well as the needs of those who will join other departments I have split the Treatise into two volumes—Vol I to be considered as the ordinary course and Vol II as appendices for the use of those who intend joining the Canal Department

The chapters on special survey and field work, on protection, on Reh, and on administration, all containing very useful information, have been added to the appendices Appendices A, C. and F. have been omitted altogether, as not of general use to-day even to the Canal Engineer. I am not in agreement with all Colonel Clibborn's remarks on the design of channels and falls.

A note on channels and a short chapter on the design of falls and weirs have been added by me, his opinions being left, as there are still many engineers who hold his views.

For practically all the rest of his Treatise, my opinions, after 35 years' service on canals in the United Provinces, are in entire agreement with his so that I have not found it necessary to make many alterations, to bring the Treatise more up to date

G T ANTHONY,

Retired Chief Engineer, Irrigation Works United Provinces
and Late Professor of Civil Engineering
Thomason Civil Engineering College, Roorkee

Dated the 4th May, 1920

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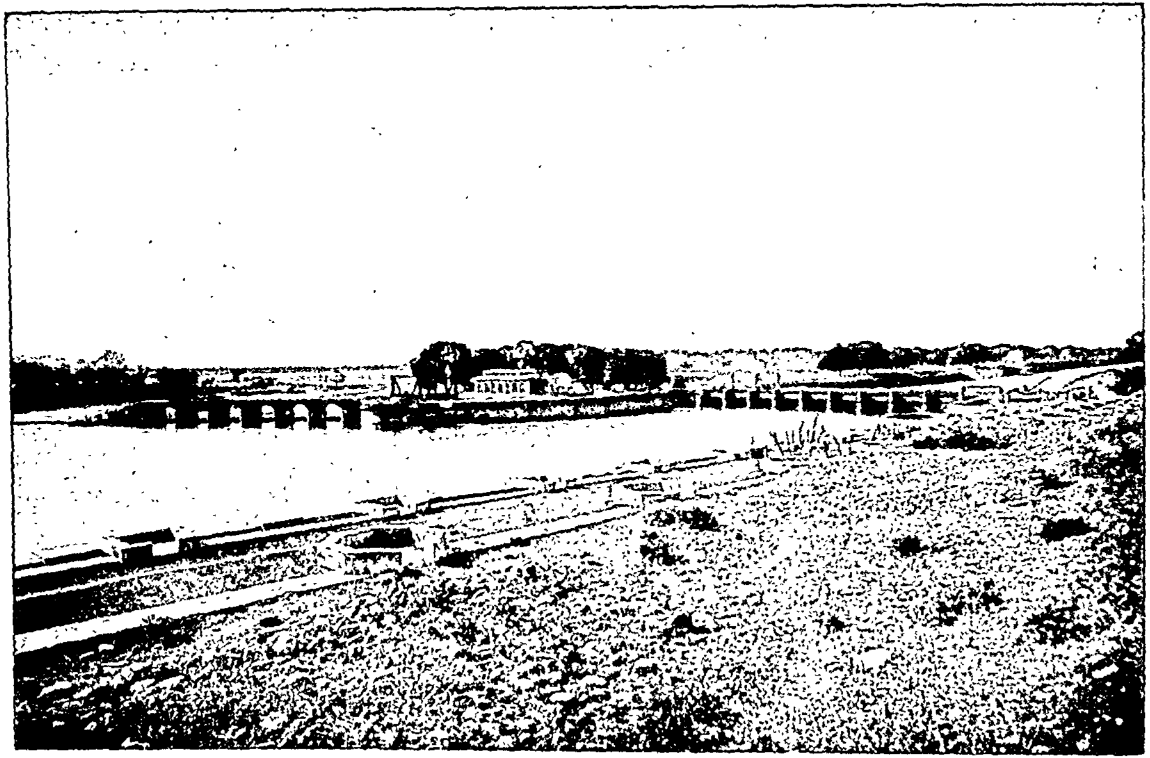

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MYAPUR DAM AND REGULATOR, GANGES CANAL.

ROORKEE TREATISE.

SECTION X.—IRRIGATION WORKS.

CHAPTER I.

INTRODUCTION

1 **Definition**—Irrigation is the operation of causing water to flow upon and spread over land with the view of nourishing and increasing the growth of plants It may be either natural or artificial Natural irrigation occurs when rain falls or when a river floods over the lands in its vicinity Both these natural systems of irrigation are occasionally controlled by artificial works, such as the raising of the edges of fields to retain the rainfall, and the making of embankments to regulate river floods Artificial irrigation comprises five important classes of works—Wells, Canals and Tanks used directly for purposes of irrigation; Drainage work, used to prevent the evils of water logging and River improvement work, which is necessary to bring rivers into a proper condition for the execution and maintenance of works

2 **Importance of Irrigation Works**—It is hardly necessary at the present day to discuss the importance of Irrigation works to countries with a small or fluctuating rainfall The immense benefits of the canals already constructed in India, Egypt, and other countries, are patent to all careful observers it is well known that these works have been successful not only in an agricultural but in a financial sense, and that they have involved the construction of some of the largest works in the world It is evident that their study by the Engineer is a necessity if his education is to be considered complete and thorough and it must also be borne in mind that in studying the details of Irrigation works the Engineer will not fail to learn in a practical manner most of the applications of Hydraulic science

Comparing the relative importance of Railways and Canals, it was recently stated by an eminent member of the English Government when referring to the Indian Famine of 1900, that the extension of Railways was not an unmixed benefit to the country as they levelled off rates, causing at all events a modified distress over very large areas Irrigation

for by properly adjusted rates, leads to careful cultivation necessitating the employment of labourers If on the other hand water is allowed to flow over the country in a wasteful manner, and if the rates are not calculated to deter cultivators from careless farming, the number of persons employed on the land will in time be reduced to the tenants and their families.

Effects on climate and health —Large Irrigation works such as main canals and tanks, are feeders of the subsoil water-supply, and thus have a distinct influence on the climate drainage and health of the country This influence is good in so far as it adds to the underground reservoir, providing a store to be used by drawing from wells most economically, because the expense attendant on lifting water a considerable height causes cultivators to take great care in the distribution. The effect of a high saturation level is, however, bad when drainage is neglected, as it causes water logging and injury to health and land Irrigation on a large scale must effect the climate making it colder and damper, particularly at night, and when the inhabitants are poor and unable to clothe themselves properly, no doubt their health suffers Fortunately the general improvement in circumstances which follows the introduction of irrigation should enable the people to protect themselves in this respect

Plantations —The banks of large canals are generally planted with trees—this is a great advantage to the tracts through which they pass on account of the shade, timber, fuel, and fruit provided. Trees and shade are a real necessity in very hot climates, and as constant extensions of irrigation tend to break village plantations up into tillage, the maintenance of permanent and well cared for plantations on the Irrigation works themselves becomes desirable Moreover, these plantations, if well managed become large sources of revenue, and being alongside water carriage are in the best position for transport

Navigation —Another important function of a large canal is the facility it offers for navigation This function is often neglected probably because the Engineer is more attracted by the manifest advantages of the result of the attention he pays to extensions and improvements of irrigation It would be better, however to take a broader view of the situation and endeavour to develop all possible sources of advantage to the people and the State, and the utilization of the fine waterways formed by great canals should not be so neglected as it has been in many cases in India at all events Canals are now designed with lower velocities, traffic up stream, should not be so difficult as on the older canals

Bathing, etc.—The domestic advantages of Irrigation works should not be overlooked. The facilities given for bathing and watering cattle must be greatly appreciated by the inhabitants of the towns and villages situated near the banks.

Water-power.—Water-power is frequently made available for use by the construction of canals and tanks. In India up to the present time this source of revenue and great advantage to the country has been to a large extent neglected, owing mainly to the fact that the sites of the power are frequently far removed from manufacturing centres. Electrical transmission of power offers such a simple solution of this difficulty, that we may look forward to seeing a great advance in a few years' time, and probably many great cities may soon owe their lighting, ventilation, and commercial prosperity to the same beneficent work that supplies them with food. At Bahadrabad, Mile 7 Ganges canal, a hydro-electric installation giving 600 B. H. P. has been put up, to work the pumping and other plant at Bhimgoda where the permanent headworks are building. The distance from the power station is 12 miles.

4. Irrigation in cold climates.—In European and other countries with a temperate climate, irrigation is occasionally practised, mainly for meadow watering. The subject is outside the scope of the present work.

5. Irrigation system in Egypt and Italy.—It is well known that the Egyptian irrigation system is founded on Indian practice. In a similar manner the Indian system was started by officers who had visited and studied Italian irrigation; and indeed Italy may well be considered the parent country in the science of the distribution of water. Both the Italian and Egyptian Irrigation works are thoroughly well described in existing publications, and it is not necessary to treat of them in this Manual.

CHAPTER II

WELL IRRIGATION—SOURCES OF SUPPLY OF WATER FOR WELLS

1 **Definition** —Wells are merely holes of varying dimensions sunk from the ground surface into the water bearing strata lying below Wells may be merely simple holes in the natural soil entirely unprotected or partially protected or entirely protected with an impermeable lining except at the aperture for water entrance The different forms of wells will be more particularly described in another paragraph

2 **The Source** —The *source* of the water supply of wells is the rainfall which absorbed by the soil permeates to underground reservoirs where it is retained more or less perfectly by natural causes In some instances the rain water as it falls passes directly to the subsoil reservoir but generally speaking it may be assumed that the main supply is derived from percolation through the beds of depressions filled with rain water permanently or temporarily

3 **The Reservoirs** —It will be understood that these underground reservoirs are not hollows filled with water pure and simple but consist of gravel sand or any soil of an absorptive nature saturated with water which cannot pass away below on account of some retentive substratum and which can only pass slowly away at the sides on account of the natural frictional and other resistances which the constitution of the soil offers to the free flow of water through it

4 **Artesian basins** —These conditions are of course general and are frequently varied in particular cases such as those conformations of strata which form an Artesian basin In these cases practically the only exit is vertically through a natural or artificial opening

5 **Rock hollows** —In some situations actual hollows filled with water are found these usually occur in rock patches isolated in large areas of sandy soil Remarkable examples of this class of underground reservoirs are met with in the Western Australian desert These hollows as far as yet discovered are too small to be used for irrigation but are most advantageous for drinking purposes

A consideration of the relative contours of the ground and subsoil water surfaces in any particular locality, will elucidate the questions regarding underground reservoirs in sandy or percolative soils, and it must be borne in mind that a good understanding of these questions is necessary because the great reservoirs for well supply of hot countries lie in these soils

6. **Subsoil water levels.**—*Plate* I shows five cross sections of the country between the Ganges and the Jumna rivers in the Fatehpur District of the North-Western Provinces, India. These sections lie north and south of the town of Fatehpur, are about 5 miles apart, and as nearly as possible at right angles to the general direction of the rivers. These sections were taken in 1883, long before the introduction of Canal irrigation to this tract, and the levels of the subsoil water surface shown are therefore entirely due to natural causes. It may be mentioned here that these sections do not show any singular or abnormal conditions—they indeed may fairly be taken as representative types of the probable levels of subsoil water in flat tracts of country with *moderately absorptive soils* and situated at a distance from the hills.

These sections are very suitable as specially marked illustrations of the usual condition of the subsoil water contour, being taken over a narrow elevated plateau with rapid slopes to the bounding rivers, and considerable variation in the nature of the ground surface: the results of the supply and withdrawal of water are therefore more clearly marked in these examples than would be the case with a broad flat *doab** of a more uniform character.

7. **Subsoil level observations.**—These subsoil water contours show the levels of the water surface both during the hot months of the year when it is lowest, and towards the end of the rains when at its highest level. The observers ran a line of spirit levels at right angles to the bounding rivers, and connecting with the wells passed at reasonable distances on either hand, actually measured to the lowest level met with during the months of May and June, at the same time recording the highest level the water reached after the rains on the results of careful enquiries from local authorities. These observations were made by trained men, at intervals of at least one mile apart,† and as far as possible from wells used for drinking purposes only, for as, will be seen later on, observations from irrigating wells would be liable to lead to erroneous conclusions.

8. **Characteristics of water contours.**—A careful examination of these sections will show that the subsoil water surface is irregular, is often far above the highest flood level of the bounding rivers, has a fairly constant shape or contour during the year, and that it is raised by the rainfall.

* Vernacular for the land lying between two bounding rivers.

† It was impossible always to find wells on the high slopes to the main rivers, so the contours shown are in places approximate.

9 **Constancy of outline** —This irregularity and constancy of outline is due to the sources of supply of rain water to the subsoil being special and confined to particular areas and to the resistance which the sandy subsoil offers to the free travel of water through it

10 **Rainfall damp** —At various times practical experiments have been made to determine the depths to which heavy rainfall or irrigation moistens the soil The results have almost invariably shown that the ordinary depth of damp is only a few inches or feet this proves that a large quantity of water and a considerable period is required for percolation to reach to great depths The experiments were naturally made in fields or tracts under water for a short time only, and it is clear that percolation to the subsoil must take place through the beds of swamps and tanks except perhaps in the case of very sandy ground where the whole of the rain is absorbed as fast as it falls and being thus to a great extent preserved from evaporation passes slowly to the subsoil reservoir.

11 **Local sources of supply to the subsoil** —If a tract of country is examined by careful water contouring it will be found that the elevations in the subsoil water surface correspond with the position of large flooded surface areas, and other likely local sources of supply, this peculiarity, viewed in conjunction with the fact that these high level subsoil water contours are so frequently far above the flood level of the bounding great rivers proves that percolation from rainfall is the main source of supply to the subsoil reservoirs

12 **Percolation from canals** —The minor perennial streams traversing the *doab* at a high level and canals or other large water courses are also sources of supply the method by which water passes to the subsoil from such sources is shown by *Fig* 1 *Plate* II

13 **Cone of percolation** —The cone of percolation is not fully formed for several years after the opening of a canal and probably never connected at all with the normal level in the case of small channels or those which are periodically open and closed The slopes of the sides of the cone are parabolic and vary with the character of the soil between the ground surface and the normal level, being flat in coarse sand and fine gravel and abrupt in clay In the ordinary soils of the great Gangetic valley the average slope is about 1 in 250 or say 20 feet per mile but the slope will at once be reduced if the free exit of water at the base of the cone is stopped by say a bed of clay or an elevation in the normal level and in time the surface will become level

It is evident in the case of a new canal that the loss by percolation will be great until the cone is filled up, and after this has happened the loss will be only the quantity passing off to the subsoil reservoirs by the exits at the sides of the cone.

14. **Limits of side slope.**—This limit to loss of water stored in the subsoil is due to friction, and is a very useful provision of nature. If the passage of water through sandy subsoils was free and unobstructed most of the Indian *doabs* would be deserts, wells would be financially impossible and the cultivation of crops both difficult and hazardous.

15. **River springs.**—There is of course a steady, though very slow, drainage down the high slopes into the *rivers rendering* them perennial in ordinary soils; when the soil is very loose and open the contained water drains off rapidly, the country becomes a desert, and the rivers have dry beds until rain again falls.

16. **Movement of subsoil water.**—The same steady drainage down slopes occurs in the interior of the plateaux as well as on the edges, tending to flatten out the contours and fill up hollows, and as this action is unceasing, it will be seen that practically speaking the surface of the subsoil water is almost constantly in slow movement.

17. **Percolation from the hills.**—It *has* been suggested that the vast subsoil reservoirs in the plains of India are *supplied by Artesian* pressure from water stored in the hills. A little reflection will, *however*, show that this is impossible, owing to the great distance from the hills; the want of a continuous clay bed over the water-bearing stratum, and the comparative flatness of the plains, which in itself would prevent *any* appreciable flow of water, owing to the great frictional resistances offered by the soil. It is also doubtful whether there is any very reliable evidence that the hills themselves are great storage reservoirs. There are springs, streams and rivers in the hills it is true, but not in great excess. Many large tracts in the hills appear quite dry shortly after the rains and the great floods of the monsoon show that a far larger proportion of the annual rainfall flows off the hill slopes down the rivers directly into the sea than is absorbed and given out by springs in the cold and hot weather. It will be found that the whole volume of spring water discharged in six months by a great river like the Ganges would hardly suffice to cover 1,000 square miles of country to the depth of the annual rainfall.

18. **Tarai springs.**—It must not be concluded from the above that percolation from the hills has no effect on the plains, on the contrary, the

effect is very marked, but extends only to tracts lying comparatively near at hand.

19. **Soils near the hills.**—The diagram *(Fig. 2, Plate II)* shows the usual disposition of soils near the hills, viz., first, open soil of boulders, gravel and sand *(Vern. Bhabar)*, then heavy clay *(Vern. Tarai)*, then light clay *(Vern. Mar)*, then the ordinary sandy loam of the plains. Percolation from the high hills checked by the Tarai clay rises in springs in that tract; these springs generally form swamps, from which streams issue, becoming rivers lower down in the plains, where they are very useful for local irrigation. Even the smaller hill streams and the springs which issue from the foot of hills disappear entirely in the open gravelly soil of the Bhabar to reappear again in the Tarai. The surface of the subsoil water in the Bhabar, far below the ground level and beyond the reach of wells is probably nearly horizontal, and the Bhabar soil thus probably forms the real hill reservoir.

20. **Limits of percolation from the hills.**—There is but little information available as to the extent and dip of the Tarai clay bed under the plains, but it is probably that it overlies the Bhabar gravel for a considerable distance until it nears or meets the hill bed rock. If this is so, a little consideration will show that this clay bed must practically limit direct percolation from the hills, and also that good Artesian supplies should be available by piercing it. *(See Fig. 3, Plate II.)*

21. **Supply to subsoil from tanks.**—Artificial tanks often form very valuable means of conserving the rainfall and conveying it to the subsoil by percolation to be afterwards used for irrigation from wells. A tank may in this manner, combined with the subsoil, form a very large reservoir, and as irrigation is always conducted more economically from wells than by direct flow, it is evident well irrigation is the best method of using tank water in countries with a short rainfall.

22. **Supply from irrigated land.**—In paragraph 16 of this Chapter, it was stated that the percolation on irrigated land, as a general rule, only moistened the soil for a few inches or feet at most This is quite true for ordinary classes of irrigation, but does not always apply where water is kept continuously on the land, as in some cases it is for rice, or where the natural subsoil surface water level is very near to the ground surface.

There is no information in India to the quantity of water returned to the rivers from irrigation in this manner, but in America, where the local conditions often allow of irrigation water being used over and over

again, the matter is one of considerable interest, and observations made in 1894-95 of water returned to the Platte river from the Poudre valley irrigation channels, showed that the return was one cusec from 700 to 1,000 acres irrigated. It should be mentioned that the waterings in America seem profuse compared with those usually given in India, and the soil was probably more open and porous.

23. **Rate of travel of underground water.**—It is most difficult to estimate the speed of the movement of underground water; this manifestly must depend on the side slopes and the soil, both variable quantities. Experiments and observations made both in India and America seem to show that a rough average of one mile per annum may be accepted for ordinary localities. Additional and more accurate information on this question would be valuable and help to solve many sanitary questions.

There are, however, many conditions interfering with observations which may invalidate the results; thus, if the experiments are made on soil previously dry, the rate of advance may sensibly differ from what it would be in soils previously wet. If again observations are made say from a canal to a low-lying river at some distance, the increased flow of springs at the river may be due either to the transmitted pressure, as occurs in a long pipe filled with water, to which an addition is made at the upper end, or it may be due to the water which actually left the canal—it is certainly difficult to actually identify the water leaving the canal.

24. **Quantity of water available.**—The actual quantity of water an underground sandy reservoir will hold must depend on the character of the soil; it may be assumed at one-third of the bulk of the sand but all this will not be available for immediate supply to the well as a certain quantity must remain entangled in the soil, and it is probable that not more than one-fourth drains in at once when the well is drawn upon.

The Mota.

25. **Definition.**—*Mota*, *Matbarwa* and *Nagasan* are local vernacular terms applied throughout the Gangetic *doab* to beds of clay, indurated sand, kankar or other hard material which are often found lying a few feet more or less below the surface of the water in the subsoil. When clay beds occur, as they often do above the water surface, they are not termed *Mota*. These beds are obviously due to local action occurring at the period of the deposition of the soils of the *doab*—action similar to that

which even now may be observed producing clay beds in the backwaters of Deltaic rivers

Similar beds are certain to be found in all large plains lying below denuded uplands, particularly when the denudation has been caused by fluvio marine action

26 **Occurrence of Mota** —Throughout the United Provinces in India, where well irrigation is extensively practiced, *mota* beds are found, but they are not in one continuous layer, nor are they universal, they are of varying thickness, at different depths below water, and may be from a few feet to many square miles in area

These beds are thus as it were isolated islands of hard material lying in a vast deposit of sandy porous soil loaded with water, and as will be seen later on, their occurrence renders the withdrawal of irrigation water a much simpler problem than it would be otherwise

The existence and use of these beds are well known to the inhabitants, and has often influenced them in fixing the sites of their towns and villages where the provision of an ample supply of water is essential.

These beds occur less frequently and are less continuous on the rapid slopes near the hills than in the lower plains where the ground surface has only a general fall of a foot or so per mile

27 **Use of the Mota** —The *Mota*, unless continuous over a large area situated so as to form a local basin commanded by high lying water bearing starta does not act so as to give an Artesian supply to the well sunk into it The condition of *mota* beds indicated above may, and possibly does, occasionally occur, but in the ordinary course an isolated patch of *mota* acts merely as a beam to support a well resting on its surface, and fed with water by a hole bored though it to the sand below. *Mota* beds are useful both for unlined partly lined and masonry wells but their great advantage lies in the fact that they give perfect stability to a heavy masonry well which could not remain unmoved while in steady use without some such solid support

28. **Entry of water to a well.**—To thoroughly understand this matter, it is necessary to consider how water leaves the interstices of the sand in which it is entangled and enters a well.

The diagram (*Fig* 4, *Plate* II) shows a masonry well resting on a stratum of *mota* clay, indeed partly sunk into it to prevent any chance of water finding its way into the well under the edge of the curb, if this occurred, sand would be drawn into the well with the water, and by slow degrees a cavity would form outside the masonry ring which would in

time endanger the stability of the work. It will be seen that a hole about 6 to 9 inches in diameter is bored through the *mota* to connect the well with the sand and water below. Now when by drawing it up water is removed from the well the surface is lowered, and water and sand together are drawn up into the well through the hole in the *mota*. The sand comes up with the water on account of the velocity through the small orifice, and because the surface of the sand below the *mota* is not of sufficient area to give up the quantity of water removed from the well without carrying some sand particles with it. This removal of sand and water together goes on steadily until the area of the surface of the hollow, which is gradually formed below the *mota*, is large enough without disturbing sand to give up water at the rate it is drawn from the well.

In practice this sand is removed from the well from time to time as it collects in it, finally nothing but pure water enters the well, but if at any time the rate of removal of water is increased, sand will again be drawn up until the balance is restored.

29. **Wells on pure sand.**—*The usefulness of the mota* is now apparent; without it the well would rest on pure sand, and no hollow could be found, moreover the quantity of water which could be drawn with safety from the well would thus be limited to that which could be delivered from an area of sand equal in extent to the area of the base of the well. If this were exceeded sand would be drawn in with the water and the well ring would slowly subside.

These remarks apply to wells used for irrigation from which large quantities of water are drawn. Small supplies for domestic purposes are often taken from wells resting on pure sand without injury or disturbance, but it will be evident at once that the chances of obtaining a pure supply for drinking purposes are much increased by using *mota* wells.

It would be possible to do without a *mota* for an irrigation well if the area of the base of the well was made large enough to expose a sufficient surface of sand, but the expense of this would of course be very great.

30. **Unlined Wells on Mota.**—The *mota*, as will be seen, really acts as a beam to support a masonry well over the inevitable hollow below. Unlined wells where there is a *mota* are usually sunk through it for the whole diameter of the well, and the water is drawn up directly from the hollow below.

The *mota* is not so useful for dry brick or stone wells, because the water above the *mota* filtering through the sides of the well prevents the

head acting properly on the water under the *mota* In this case the hole bored through is also liable to be choked up with sand drawn in from the sides.

31 **Artificial Mota** — It is sometimes necessary to provide an irrigating supply from wells in tracts where no *mota* is available. In this case the usual practice is to sink large numbers of unlined wells which last one or two seasons only, and then fall in The question of making artificial platforms with concrete to imitate the natural *mota* has often been considered, but it is extremely difficult to estimate the dimensions of the hollow that will form in each particular case, and the cost of construction would certainly be very great. The best method of experimentally determining the size of the hollow would be to test with a small artificial *mota*, and a fixed draught of water in a temporary well, and then calculate on the results of the experiment for larger draughts

The experiments carried out at the College, Roorkee, in 1895, on the passage of water through sand showed that approximately one third of a cubic foot of water was passed through one square foot of sand in 24 hours for each foot of head of water on the sand the length experimented on was 100 feet. The discharge increased considerably when the distance from the head was decreased, it varied inversely as the distance Heavy discharges, particularly when the head was close, disturbed the surface of the sand greatly

The sands experimented on were those common to the rivers in the Gogra Indus *doab* of Northern India, the actual quantity of discharge through any particular sand was of course influenced by its quality

These figures do not allow of accurate calculations being made for the size of the hollow under the *mota*, but they do prove that it must be of considerable area Roughly they show that a well giving 300 cubic feet per hour with a 9 foot head, would require a hollow of 2,400 square feet area Other methods of obtaining large supplies of water from sandy strata will be treated of in the section dealing with construction of wells.

32 **Drainage cones** —The rate at which water can be drawn from any given well must be determined experimentally if strict accuracy is required As far as *mota* wells are concerned, it will be seen from the preceding observations that the diameter of the well does not influence the result The rate depends on the character of the water bearing stratum and the depth to which the well is sunk below the subsoil water

surface. The latter item again depends on the position of the *mota*, and its thickness, for if the *mota* is very thick the well may safely be sunk into it, care being taken to leave a sufficient depth of *mota* below to support the weight of the well. Again, if a large quantity of water is required, and the *mota* first met with is near the subsoil water surface, borings can be made to find if a second *mota* more favourably situated lies below, in which case the well can be sunk with advantage to that depth.

An inspection of the diagram (*Fig.* 5, *Plate* II) will show that the maximum volume which can be drained if the water surface in the well is lowered from W to X is the cone AB, BC.

The side of the cone AB, etc., will slope at the normal declivity of the material of the water-bearing stratum (*see* para. 14). After this cone is drained the only water which can enter the well will be that slowly finding its way along the sides of the cone from the high levels outside, in the same manner that rivers are fed by percolation from high table-lands.

In practice irrigation from wells is never carried on so as to drain the supply of a well to this extent, and the volume extracted each day is usually replaced in the cone during the night when the well is idle.

A calculation of the distance to which a well actually affects the subsoil water surface in particular localities, will be useful for fixing the distance apart at which wells should be placed so as not to affect each other.

It will be seen that the total volume of water commanded by a deep well is very large, but the volume of the water-bearing strata actually drained by an ordinary day's work at irrigation is comparatively small.

Since 200 to 300* cubic feet per hour is above the average supply of irrigating wells in the North-Western Provinces, and the Punjab, and the ordinary working day is 8 to 10 hours, the cubic content of strata drained will ordinarily not exceed 10 to 12,000 cubic feet.

Construction of Wells.

33. **Classes of Wells.**—The three main classes of wells for irrigation are—

I. Wells with a masonry lining resting on clay and fed through the clay or *mota*.

II. Wells with a dry brick or stone lining fed through the lining by percolation.

III. Wells unlined by any permanent hard artifical material.

* Much higher discharges are obtained of course from special wells.

34. **Class I.**—This class of well is the most suitable for irrigation. It may be considered a permanent source not being liable to deterioration or easily injured. Some details of construction have been referred to in previous paragraphs, but two important methods of connecting the upper masonry steining with the *mota* may be illustrated here. (*See Fig.* 6, *Plate* II).

Double Mota well.—*Fig.* 6 shows a method of connecting with a lower *mota* by a small interior well. This can easily be built up by excavating out the clay of the *mota* after the upper cylinder has been firmly embedded in it preventing the entry of water from outside. It would be both expensive and difficult to sink the large upper clyinder itself through the clay—the joint between the two wells is made with concrete.

Tube well.—In *Fig.* 7 we have the case of a *mota* situated so low that the expense of sinking the cylinder becomes prohibitive. In this case a pipe can be used to connect the steining with this *mota*, the head of the pipe being fixed with concrete.

Pipes of wood or iron may be used under water: suitable wood lasts a long time, but is more difficult to sink than iron. The internal diameter of the pipe is important. Mr. W. J. Wilson who made several experiments with tube wells in the United Provinces shows the heads lost as *follows*:—

Table showing the loss of head in pipes of different diameters.

Diameters of pipe in inches.	Velocity of water in feet per second.	Head due to velocity $= h$.	Loss of head at the two ends of the pipe $= 1 \cdot 5h$.	Value of c for incrusted pipes.	Loss of head due to friction in— 1 foot of pipe.	50 feet of pipe.	100 feet of pipe	Total loss of head in— 50 feet of pipe.	100 feet of pipe.
Discharge=900 cubic feet per hour=0·25 cubic foot per cusec.									
3	5·10	0·40	0·61	0·0133	0·0857	4·29	8·55	4·90	9 18
4	2·87	0·13	0·19	0·0125	0·0191	0 96	1·91	1·15	2·10
5	1·84	0 05	0·08	0·0120	0·0060	0·30	0·60	0·38	0·68
6	1·28	0·025	0·04	0 0117	0·0024	0·12	0·24	6·16	0·28
12	0·32	0·002	0·002	0 0108	0·00007	0·004	0·007	0·006	0·09
Discharge=1,200 cubic feet per hour=0·33 cubic foot per cusec.									
3	6·79	0·716	1·07	0·0133	0·1528	7·64	15·28	8·71	16 35
4	3·83	0·227	0·34	0·0125	0·0340	1·70	3·40	2·04	3·74
5	2·44	0·033	0·14	0·0120	0·0106	0·53	1·06	0·67	1·20
6	1·70	0·044	0·066	0·0117	0·0042	0·21	0·42	0·23	0·49
12	0·42	0·003	0·005	0·0108	0·00012	0·006	0·012	0·011	0·17

Diameters of pipe in inches.	Velocity of water in feet per second.	Head due to velocity=h.	Loss of head at the two ends of the pipe=$1 \cdot 5h$.	Value of c for incrusted pipes.	Loss of head due to friction in—			Total loss of head in—	
					1 foot of pipe.	50 feet of pipe.	100 feet of pipe.	50 feet of pipe.	100 feet of pipe.
	Discharge=1,800 cubic feet per hour=0·5 cubic foot per cusec.								
3	10·19	1·61	2·41	0 0133	0·3428	17·14	34·28	19·58	36·72
4	5·73	0·51	0·77	·0·0125	0·0705	3·83	7·65	4·60	8·42
. 5	3·67	0·21	0·31	0·0120	0·0240	1·20	2·40	1·51	2·71
6	2·55	0·10	0·15	0·0117	0 0094	0·47	0·94	0·62	1·09
13	0·64	0·006	0·009	0·0103	0·00027	0·014	0·027	0·023	·036

The quantity of water estimated for in this table is much greater than the usual discharges obtained from any but the largest irrigating wells. 200 cubic feet per hour for a single lift well is a good average discharge, and wells with four lifts and over are decidedly rare.

Sinking well cylinders.—The method usually adopted in India for sinking masonry wells is simple and efficacious. A pit is excavated on the site of the proposed well as deep as possible without shoring. On the bed of the pit a wood or iron curb is placed, and the masonry cylinder is then built up to 10 or 15 feet above the ground surface. When the masonry has set hard enough, the soil is excavated from within, and the cylinder slowly follows the excavation into the ground. When water is reached the process is continued with an excavator or dredger; when the top of the cylinder has been sunk to the surface of the ground masonry work is resumed, and it is built up to the height required. Great care is taken to keep the cylinder properly vertical while being sunk. In pure sand very little difficulty is met with in sinking in the manner described, but with clay or other hard material it becomes necessary to load the masonry ring to force it down.

35. Depth to which wells should be sunk.—It is said that in order to ensure an ordinary *mota* well giving sufficient water in a year of drought, the cylinder should be sunk 25 feet below the average percolation level. This allows for a fall in the level of subsoil water of 11 feet during a year of drought, and an additional reduction of 10 feet when the well is being worked leaving still 4 feet in the well to fill the bucket or lift. It is possible that the fall of the water surface from working, and also that caused by drought, is over-estimated in this case, but it is evident that no exact information can be ascertained in tracts when other wells are not available for reference until a sample well has been made and worked for some time.

36 **Masonry percolation wells** —As there are many situations without *mota* in which irrigation from wells is desirable and yet unlined wells will not stand attempts at various times have been made to intro duce water from a sandy stratum into a masonry well without causing subsidence of the cylinder

None of these attempts have been thoroughly successful but fair supplies have been drawn from wells partially filled up with ballast broken small or fine gravel through which the water filters without carrying up much sand

Probably the best method of overcoming the difficulty would be to sink the cylinder only far enough below percolation level to give the requisite head and serve as a reservoir for the bucket or lift to work in and to drive a pipe 30 to 50 feet below the bottom of the well cementing its head to the well bottom with a concrete plug

The hollow which would form at the lower end of the pipe would be far removed from the well and not likely to endanger it and this hollow could be partially filled up from time to time by passing fine gravel down the pipe

Fig 8 *Plate* II shows a possible method of obtaining a large supply of water by pumping from a sandy substratum the dry pump well being situated at a safe distance from a well built of dry brick or stone sunk to a sufficient distance below the percolation level and filled with gravel in which the suction pipe is embedded

As it is probable that after pumping for some time the gravel in this well would sink into the sand below for some distance the well should be left uncovered at first to allow of additional gravel being filled in from above

37 **Class II** —In wells of this class water passes into the cylinder or reservoir through the sides which are porous and this style of con struction is cheap and effective in gravel or coarse strata but it is somewhat difficult to understand how it can answer in fine sand However Mr Bull C E has built some wells in which all the bricks from the curb to within a few feet of the ground level are laid dry and it is said that little or no difficulty is experienced from sand coming in through the joints Mr W J Wilson states that there can be no doubt that if the steining of a percolation well can be completely surrounded by a layer of small material such as broken brick (*see Fig* 9 *Plate* II) the efficiency of the well will be greatly increased

The same authority recommends the following details of construction for the lower 5 feet of the steining:—The bricks to be set in mortar, above this dry to a height of 4½ feet, then 1 foot in mortar, followed by 4½ feet dry, and so on, until the cylinder has reached a height of 26 feet, above which to the top the bricks to be set in mortar, the cylinder to be sunk 30 feet, and a plug of concrete 5 feet in thickness to be put into it.

38. **Class III.**—*Kucha* wells may be used either with or without a *mota*. In some situations unlined wells may give a good supply and last for hundreds of years, viz., where there is a very thick bed of clay extending from near the surface of the ground to below percolation level and overlaying a bed of sand. The ordinary form of a *kutcha* well, where there is no *mota*, is a broad pit in the ground sunk to just above percolation level, below this it is much narrowed and lined with fascines or plaited grass through which the water from the sand oozes into the pit (*see Fig.* 10, *Plate* II). This class of well rarely lasts more than one season, as it is affected by the rainfall and rise in percolation level.

Fig. 11, *Plate* II, shows a *kutcha* well with the *mota*. If the percolation level is below the *mota* top surface the well with care may last a few years, but if only a few feet even above it, maintenance is very difficult.

Cultivators are often very ingenious in their attempt to preserve *kutcha* wells, as they can be very cheaply built in situations suitable for the irrigation of their crops.

Special advantage of temporary wells.—It will be easily understood that as the situation of the crops requiring irrigation must change from season to season according to agricultural necessities, the *kutcha* or temporary well has a great advantage in economy of water over a permanent well. The temporary well can be placed in a position suitable for irrigating the season's crop without involving a long water-course, while the position of a masonry well being fixed, the water-course in many seasons must be greatly extended if the well is to irrigate the full area it can command. Now the loss in carrying small supplies of water in earthen water-courses is very great, and in some soils quite prohibits irrigation, so that temporary and inferior in supply though they be, there are cases in which *kutcha* wells are financially superior to permanent ones.

39. **Cost of construction.**—The cost of a masonry well mainly depends on the distance from the ground surface to a useful *mota*, the

character of the soil also influences the rate for sinking. The expenditure may be subdivided under the following heads, viz.—

(i) Boring to determine the nature of the strata.
(ii) Excavation of pit and refilling.
(iii) Curb.
(iv) Masonry in cylinder.
(v) Sinking.
(vi) Fixing into clay bed or *mota*.
(vii) Boring hole through *mota*.
(viii) Clearing sand and getting into working order.
(ix) Fittings for lifts.
(x) Cost of lifting.
(xi) Tools and plant.
(xii) Establishment.

When a well is constructed by the owner or occupier of the land the actual outlay on many of these items will be very small, and experience has shown that the best method of extending irrigation from wells is for the Government or landlord to make money advances at a low rate of interest to occupiers, allowing them to select the site and construct their own wells. Assistance can with great advantage be given also by the provisions of tools for boring, and trained expert advice to help those inexperienced over special cases of difficulty.

The cost of wells, classes II and III, is very small compared with that of masonry wells—indeed *kutcha* wells (class III) are generally constructed by the cultivators themselves without any actual money outlay.

40. Methods of raising water from wells for Irrigation.—*Steam.*—Steam power is not in general use in India for raising water from wells for irrigation because individual cultivators cannot bear the capital cost of the installations, and the people are not yet sufficiently advanced to combine for such a purpose. The quantity of water which can be raised from individual wells is too small for economical working with steam, and the difficulties in the way of trained supervision and repairs over a series of small machines scattered through country districts at a distance from workshops would be very great.

Steam power is used on railways and in mills and factories in India for pumping from large wells in an economical manner, and may no doubt be so used for irrigation to some extent in the future, but it is probable the extra height to which water has to be pumped for industrial, compared with agricultural purposes, tends to make the steam power working economical.

Electrical working.—It has been noted that percolation from large canals raises the subsoil water level to some disance from the main channels, also that canals are sources of water-power. This water-power might well be employed in electric pumping from wells for irrigation along banks of main canals, and this procedure is the more desirable, because it has always been found injudicious to allow direct irrigation from large channels, and thus cultivators, apparently in a much envied position close to a large supply of water, often find themselves unable to benefit therefrom.

41. **Water lifts in use in India.**—The following water lifts for wells are in more or less general use in India :—

The *Rati* or pulley.
,, *Denkli*, *Paegota*, *Lat* or lever.
,, *Mot*, *Churus*, *Pur* or bag.
,, Persian wheel.
,, Chain pumps.

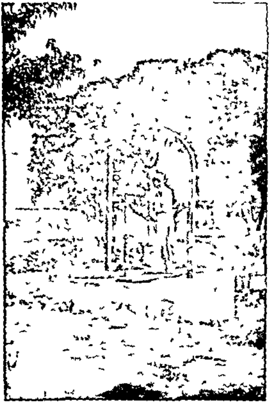
Illustrations are given of the first four of these lifts which are of long standing native design. The chain pump was introduced by European agency, and though adopted to some extent has not yet come into general use, probably on account of the difficulties of getting repairs made when the pump is out of order.

There are variations in detail in all these native lifts, but the general idea appears to be very ancient, as similar designs are found in Egypt and most Eastern countries.

The *rati*, the *denkli* and the chain pump are worked by hand ; the *mot* and Persian wheel generally by bullock power, but the *mot* in some places is worked by hand.

42. **The Rati** —The *rati* or *charki* consists of a rope passing over a light pulley fixed in a framework over the well ; the rope has an earthen pot attached to each end, and the man working pulls these pots alternately up and down. There is no loss due to dead weight lifted, and this class of lift is usually employed for garden cultivation where only small plots of land require watering.

43. **The Denkli.**—The *denkli* consists of a lever, the short end of which is loaded so as to a little more than counterbalance the weight of the rope, and empty earthen or iron pot on the long end. One man is employed lifting and emptying, and one person in the field, and they change work occasionally.



LIFT IRRIGATION—THE RATI

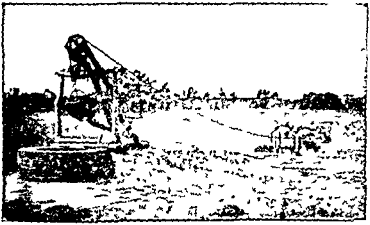


Photo Mech'l Dept. Thomason College, Roorkee.

LIFT IRRIGATION THE CHURUS

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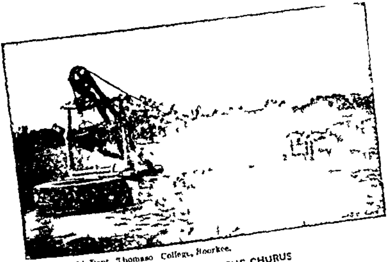

Photo Mecl l Dept Thomaso College, Roorkee.

LIFT IRRIGATION THE CHURUS

It will be seen that the man working the *denkli* has to pull slightly on the rope to lower the pot into the well, but when raising he has to exert less force than the quantity of water raised would require, and neglecting the friction on the axis, there is no loss due to dead weight if the loading is properly adjusted. When the supply admits of it, two *denklis* in one well are common, and thus the labour of one person is saved; because one man in the fields can distribute the water-power from several lifts—even 10 to 15 *denklis* are occasionally seen in different wells close together lifting into a joint water-course. This usually occurs when a good local supply near the surface is available, and is a most economical system of irrigation.

The first cost of *ratis* and *denklis* is very small.

44. The Mot or Churus.—The *mot* or *churus*, also called *pur*, is the most widely distributed lift for wells with a good supply of water. In the United Provinces, where well irrigation is extensively practised, cattle are only employed on what are called the *kili* and *lagor* systems of draught, in both of which the *churus* or leather bag filled with water is drawn up by a strong rope fastened to a wood or iron ring round which the edge of the *churus* is tied; the rope is carried over a pulley fixed on a framework overhanging the well mouth and the cattle travel up and down an earthen ramp sloped at an angle varying from 5 to 10 degrees. The *churus* or *pur* when emptied by a man standing at the mouth of the wells is again lowered down into the water and refilled.

Lagor.—When working *lagor* there is only one ramp or slope, and when the *pur* is emptied, the bullocks turn round and walk up the slope with the rope still attached to the yoke.

Kili.—The term *kili* is derived from *kil*, a nail or peg of wood, and when cattle are worked on this system, as soon as the *pur* is empty, the driver takes out the peg which fastens the rope to the yoke, and holding the end of the rope in his hands allows the weight of the *pur* to draw him up the ramp to the well. The bullocks walk up a second parallel ramp to a feeding trough fixed near the well, and as soon as the *pur* is refilled are again ready for work.

The advantages of *kili* working over *lagor* are that it does not harass the bullocks, it is easier on the driver, and it enables a number of cattle to be used at the same time, thereby saving delay and expense. Anyone who has observed cattle working *lagor* will have noticed the irritation caused by the jerks their necks get when the empty *pur* is thrown back into the well, nor do they get any food when working. *Kili* is easier on the driver, as he gets pulled up the ramp and saves time and expense, since

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two to four pairs of cattle can be worked at the same time, each pair waiting their turn. When the cattle are well trained only one driver is necessary, as the bullocks walk up by themselves to the food near the well.

In both *kili* and *lagor* working the driver usually sits on the rope going down.

Content of lifts.—The average capacities of the lifts in use in the United Provinces are as follows:—

		C. feet.			C. feet.
Rati ...	...	·33	*Mot—Lagor*, men	...	1·75
Denkli ...	...	·33	„ *Kili*, cattle	..	5·00
Mot—Lagor, cattle	...	3·00	Persian wheel jar	...	0·12

45. **Persian wheels.**—The Persian wheel is in general use in Egypt, the Punjab and elsewhere. It consists of an endless rope fitted at intervals of 1 to 1½ feet with earthenware, wood, or iron jars, and carried on a vertical drum. The drum is revolved by a simple gear with bullocks, and the jars dipping into the well water descend empty and ascend full. When they reach the top of the drum the water is tipped over into a shoot, thus giving a nearly continuous stream.

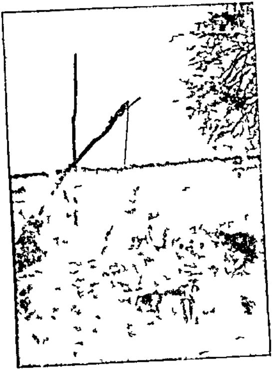
Persian wheels are worked single or double. With the single wheel one man and two bullocks are employed, and in a 40 feet deep well, with a 4-foot bucket drum, in an hour 125 cubic feet might be lifted.

Improved forms of both the Persian wheel and the chain pumps of European design are always available in the market, but as before noted regarding the chain pump, they have not been brought into extensive public use for irrigation up to the present.

46. **Aermotors.**—Mr. W. H. Moreland, I.C.S., carried out some interesting experiments on aermotors in 1897-98.* His conclusions are the small wind engines of the capacity tested viz., 12-foot wheels, are not suited for general use in well irrigation in the United Provinces. The insufficiency and uncertainty of the wind during the irrigation months make it impossible to rely on them except as an auxiliary source of power, and their use as auxiliaries is rendered objectionable by the fact that whether at work or at rest they monopolise the whole well. These engines appear suitable for small gardens where a storage tank is available, and there is not sufficient work for a pair of bullocks.

The value of the aermotor with low lifts such as are common in canal irrigation has not been tested.

* *See* Bulletin No. 11, Agricultural Series, Department of Land Records and Agriculture, North-Western Provinces and Oudh.



THE DENKL

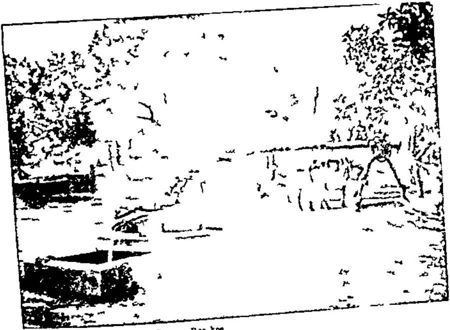


Photo. Mec l. Dept Thomason Co ge Roo kee

PERSIAN WHEEL.

It may be mentioned that Colonel Brownlow, R E, arrived at a similar conclusion many years ago

47 Quantity of water raised by different lifts —The following Table gives some figures regarding the work done by different lifts A foot ton is one ton of water raised one foot high in an hour, useful work as distinguished from gross work is the actual water raised, neglecting the weight of the lift, rope friction, etc

Class of well lift.	Total discharge in cubic feet per working day of nine hours				Foot tons per head per hour useful work
	Per pair of bullocks		Per man		
	Height lifted	Cubic feet water	Height lifted	Cubic feet water	
Rati		...	17	615	32 26*
Denkli	..	..	13 4	461	21 09*
Chain pump ..		..	15	654	30 60†
Mot—Lagor men ..			32	291	23 73*
" cattle,	33 6	2 069	..	..	56 74*
" *Kili* ..	29 0	1 314	..	..	53 6*
Persian wheel ..	20 0	1 815	..		57 1†

These results, which are the average of a large number of experiments, are very interesting in that they show that there is not much real advantage in one lift over another as far as the actual work done is concerned, but the selection of the proper lift to use is really governed by local conditions, thus, it would be absurd to use a single *rati* or *denkli* for the irrigation of a large area because the quantity of water raised would be insufficient to irrigate the crop quick enough A large number of *rati* working together into one water course might be economical, but the provision of a number of wells and labourers would be both expensive and impracticable with scattered small areas of cultivation In gardens, where wells are cheaply dug and water near the surface yet scanty, the *ratis*, *denkli* and chain pump appear very suitable. Again where wells are deep and expensive, yet water and cattle plentiful, the *mot* will give the best results in practical irrigation, and under similar conditions, but with water near the surface the Persian wheel can be used The results in the Table show that a bullock only does twice

* Calculated from results of experiments made for the papers on Construction of Wells by Captain Clibborn, published at Roorkee, 1883

† Calculated from experiments made in 1884 by Mr. W, J Wilson

the work of a man, but the Indian bullock as a rule is small, and in the experiments the men working all lifts but the chain pump, were cultivators who naturally work steadier and harder than hired labour. Moreover as irrigating bullocks have to be made to last throughout the season, and food at this period is somewhat short, the farmers do not as a rule press them more than can be helped.

A chain pump of the usual size takes four men to work it in two shifts, and as the labour was hired for the trials, the work done shows that this class of lift ought to come into favour with farmers where cattle are scarce and labourers available.

DUTY OF WELL WATER.

48. Definition of the Duty of Water.—The term duty of water, as used with reference to a canal, expresses the number of acres per annum or per season as the case may be, that can be irrigated for each cubic foot per second (cusec) of discharge of the canal channel running continuously. With wells the duty cannot be expressed thus, as there is no permanent discharge, but it is useful to determine the duty per lift from statistics collected over large areas, and under varying conditions. This duty cannot give figures applicable to any single well, because the work done annually will be influenced by the nature of the cattle, the supply of and depth to water, and the soil, but it will be found useful when applied to large groups of wells, or for valuations of the probable benefits of extension of well irrigation in districts.

The results of more than 200 careful measurements made by the author in 1881-83 are given below. These measurements extended over 20 districts of the United Provinces, and may therefore be accepted as a fair average.

It will be understood that these figures do not show what the men and cattle could do if regularly worked, but what they actually did under their own arrangements as to crops, waterings, etc.; and it will be fair to accept four acres as the area which can be comfortably irrigated by one cattle lift in the year and one acre of garden, etc., by one man with a hand lift.

Mean depth to water.	Class of lift.	*Duty in acres per annum.*	
		Per lift.	Per head.
25	*Mot—Kili*, cattle,	3·91	1·95
30	„ *Lagor* „ ..	3·47	1·73
28	„ „ men ..	2·76	1·38
15	*Denkli* „ ..	0·91	0·91
18	*Rati* „ ..	0·80	0·80

The district of Rae Bareli in the United Provinces, India, is remarkable both for the extent of the existing well irrigation and the

freedom with which farmers have taken advances for extension The aver age of 3 716 lifts examined gave three acres as the mean area irrigated in the *rabi*,* and 3 21 acres as the average area irrigated per annum

When estimating the area to allot as command per lift or well it must be borne in mind that the same land is rarely irrigated or at all events ought not to be irrigated every year unless the manure supply is ample, so that an area considerably in excess of the annual average may be allotted with advantage As the manure supply and the highest cultiva tion generally lie near the village sites the position of the well should also be considered with reference to the command

The command of a lift may be determined on the cultivated the culturable or the total area of the village or district lands On the whole the simplest and most accurate method is to determine it on the cultur able area, and I consider a village provided with one cattle lift per 10 acres of culturable area to be thoroughly protected as far as well irriga tion is concerned—10 acres is 2½ times the average annual area irrigated

49 **Potential area** —In famine times as long as the water, cattle, and men last out, wells will be drawn upon the full extent of their irrigating power and it is interesting and instructive to enquire into the area which may be considered possible from one lift

It would appear simple enough to work out this area by taking the number of days available the water lifted and the depth of watering required but the result of such a calculation would be erroneous, because of the—

Different number of waterings required by crops
 „ depths „ „ „
 „ losses in the various classes of soils,
 „ „ *according to length of water-course and other varia* tions due to climate soil, etc

It is clear, therefore, that the only sound methods of estimation is to take the results of a large number of observations as an average figure to which co efficients can be applied in special cases if necessary

When applying average figures for famine year irrigation it must be remembered that the dryness of the soils and the heavy evaporation in a dry atmosphere will necessitate extra waterings and thus reduce the irrigable area

The following figures have been arrived at for the United Provinces from a large number of observations by taking the average percentage

* *Rabi* —The cold weather season when wheat and barley etc, are grown

of crops cultivated in each district, the average number of waterings, and the mean time required to water an acre. The total period available for watering the *rabi*, or cold weather crop, has been assumed at 150 days, and 50 per cent. has been added to the *rabi* area for *kharif* crops.

Mean-depth to water.	*Lift.*		Maximum annual command per lift.
	Class.	Labour.	
28·1	*Mot—Kili,*	Cattle	8·80 acres.
32·3	,, *Lagor*	,,	7·60 ,,
32·1	,, ,,	Men ..	6·00 ,,
15	*Dhenkli* ..	,,	2·77 ,,
15	*Rati* ..	,,	2·77 ,,

It will be understood that these figures are probably the maximum possible under favourable conditions, and that they are very rarely worked to in practice.

50. Depths of waterings.—The following may be taken as a fair average of the depths of the waterings given from wells to different crops :—

Crops.	*Depth in feet.*	
	First watering.	After watering.
Wheat	·250	·186
Barley	·186	·186
Tobacco	·186	·125
Opium	·186	.125
Carrots	·186	·125
Potatoes	·186	·125
,, in ridges	·125	.093
Gardens	·093	·093
Sugarcane	·250	·250

The numoer of waterings given to each crop differ so widely according to soil, climate, and season, that it would not be of any practical use to specify them for general use.

Depths of damp.—The depths to which these waterings damp the soil below the surface vary from 0·50 foot to 1·50 feet, the mean of a large number of measurements in all classes of soils and crops=0·83 foot.

Loss in water-courses.—When water is raised from a well for irrigation it has to be carried to the fields requiring water in an artificial channel, and a certain amount of loss occurs from absorption by the bed and sides of the channel, unless it is lined with some impermeable substance such as concrete or brickwork. This loss is much more serious than is generally supposed, being no less than an average of two cubic feet per foot run of water-course during an ordinary 9-hour day's work. The loss is of course greatest in loosely made channels of sandy soil, and least in well made clay channels.

Taking the average length of water-courses from irrigation wells used in the United Provinces, it represents a loss of from 20 to 40 per cent. of area that might otherwise be irrigated by the water actually raised. This loss would practically disappear with lined channels, and is

a strong argument for improving the distribution of all irrigation water both from wells and canals

It will also be seen from the above that it will not pay to place a well far from its command nor to build very large wells unless all the lifts work into one common water-course

Cost of Irrigation from Wells.

51 **Variable conditions** —There are few wells to be found from which irrigation is carried on under precisely similar circumstances Climate affects the number and depth of the waterings given and there are marked variations in the characteristics of the cultivators, wells, and methods of lifting water.

The advantage in attempting an estimate of the cost of irrigation is that each individual well, or cluster of wells, is a fixture in its own plot of land, the boundary of which can be determined with reference to surrounding wells, and the maximum quantity of water which can be lifted in a day can be fairly well estimated.

Detail of total charge —Every crop that is watered from a well bears a charge over a dry crop, the total of which is made up from the following main heads, viz —

A. Interest on capital invested in works

B Annual charges, such as lifts and repairs

C Cost of lifting the water required.

The word *dry* is intended to refer to crops raised in lands unprovided with wells, as even when well lands are not watered owing to rain having fallen, they have still to bear the annual interest charges.

Charges on the land —The variations in A and B are so great that round figures must be more or less misleading but for general purposes of estimation the annual charge for these items may be put down at Rs 2 per acre for wells constructed by Government, and Re 1 4 0 per acre for wells constructed by cultivators for their own use, the difference is of course, due to the fact that Government has to pay cash for all work done while cultivators do a great deal personally, and can also manage cheaper in many other ways, nor is there any charge for supervision in the latter case

Net cost of raising water —The net cost of raising water per acre for the irrigation of the following crops grown in the United Provinces, given below, has been deduced from a large series of observations—these rates only cover the cost of feeding the labour employed

	Rs.		Rs.
Wheat	8·0	Carrots	10·0
„ and barley ..	7·5	Peas	2·5
„ and gram ..	7·0	Oats	10·0
Barley	6·0	Opium	15·0
„ and gram ..	5·0	Tobacco	15·0
„ and peas ..	5·0	Potatoes	12·0
Safflower	4·0	Garden	12·0
„ and carrots ..	5·0	Sugarcane	12·0
Gram	2·5		

WELLS *versus* CANALS.

52. **Advantages of well water.**—The Engineer may be called upon to consider the subject of wells from another point of view to that of construction, motive power, etc.; he may have to give his opinion as to the desirability of introducing canal water to tracts already more or less irrigated by wells. This is a very important matter, and one that deserves the most careful enquiry and consideration, because not only is there the danger of injuring an established and effective, though expensive, means of irrigation by the introduction of a cheaper method, but there is the still worse danger of using up canal water where it is not wanted, and thus leaving other tracts unprotected where it would mean wealth—indeed life—to the inhabitants.

In some respects well water is said to be more beneficial to crop growth than canal water. The general proof of this is difficult, simply because there are just as marked variations in the quality of the water from different canals as there is in that from different wells; but it is quite certain that wells have one great advantage, in that the owner can raise the water when it pleases himself, and thus arrange his waterings to suit exactly the wants of the crops, while with canal water he often has to wait his turn, and may not be able to procure water at the time most favourable for his crop. It is, however, only fair to note that this perfection of arrangements as regards well water does not stand the test of famine or any excessive demand, and that modern improvements in canal distribution are steadily tending to more regular, though necessarily restricted, supplies of water.

Investigation necessary.—When making enquiries of the nature referred to in this paragraph, the first duty of the Engineer is to determine

PLATE 1

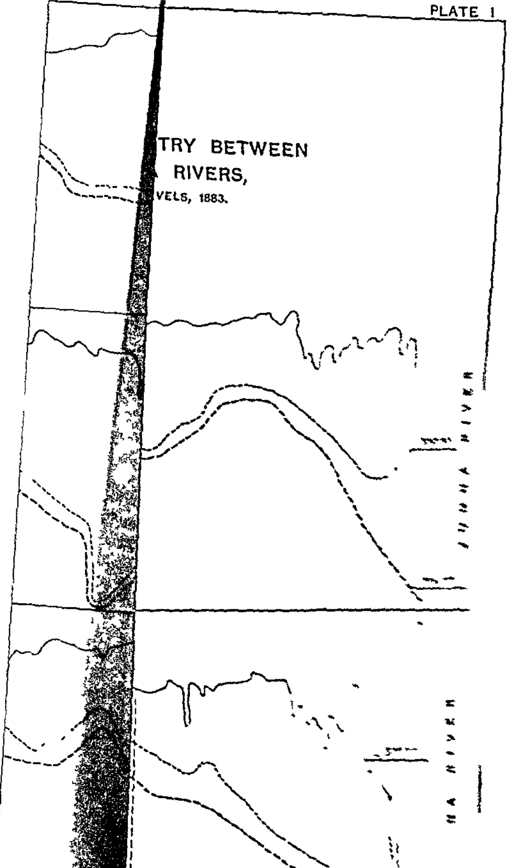


Fig 2

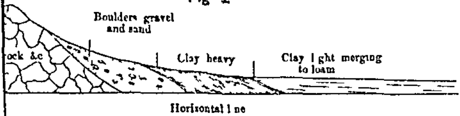
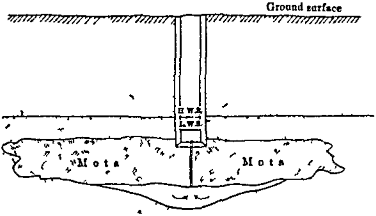


Fig 4



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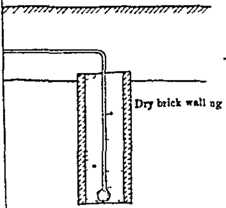


Fig 9

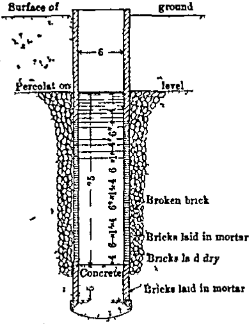


Fig 11

Photo Zinco June 1924—No 7540 2 800

CHAPTER III.

CANAL IRRIGATION.

1. Canals and Navigation.—Canals are divided into two great classes—those of Irrigation and Navigation. It is of the former class we have to treat now, though a large Irrigation canal may, and should, be laid out as a rule so as to serve for Nagivation as well, the velocity of the stream being made as gentle as is consistent with its primary uses, so as to afford facilities for boats to ascend against it as easily as possible.

Without special means of traction and special attention, Navigation cannot be *expected to be very successful* on Irrigation canals, for the conditions of an Irrigation canal are that it should be carried at a high level, so as to have sufficient head to water the adjoining lands; that it should follow the watershed so as to maintain this command and not interfere with drainage, and that it should have a running stream to provide the water necessary. Irrigation canals, moreover, should avoid the vicinity of large cities or towns as much as possible.

The ideal Navigation canal, on the contrary, should have a still-water channel, as direct as possible, so that navigation may be equally easy in both directions and it is most economically constructed at a low level. Navigable canals should also approach conveniently near to large centres of traffic.

2. Brief History.—Irrigation canals are practically *unknown in* England except for watering meadows, since the rainfall in that country is so considerable that the operations of the former, as far as regards water, are generally directed to draining the superfluous moisture out of the soil. In South Europe, where the climate is hotter and drier, there are many fine canals which have been well described by the late Colonel Baird-Smith and Colonel Sir C. Scott-Moncrieff. In India, Irrigation works have been used from time immemorial, and Indian Engineers have within recent years developed a magnificent system of irrigation from the Nile in Egypt.

The first canals opened [illegible] English [illegible] which [illegible] had been made two or three [illegible] years [illegible] Muhammadan Emperors [illegible] been [illegible] as [illegible]

resorted to, to bring them into use and make them pay as quickly as possible. At first too, our Engineers had no experience of such works, nor was there any available source from which it could be derived Much, therefore, was done by rule of thumb, until the laws of running canals may be said to have worked themselves out On the Ganges Canal, for the first time, there was new ground to work upon Sir Proby Cautley successfully overcame the difficulties attending that vast project as far as regarded the main canal, and his able successors in the Indian Irrigation Department have from time to time, developed and systemised arrangements for the distribution of water which have conferred the greatest benefits on the country Much undoubtedly yet remains to be done before the system can be said to be perfect, but practical advances are being steadily made all tending to economy of water, security of the soil from injury, and an automatic method of distribution

What Sir P. Cautley did for Northern India Sir A. Cotton carried out in the South, and the great works from the Cauvery, Godavery and Kistna remain as monuments of his energy and skill

Irrigation works have recently been started in both Australia and South Africa and will no doubt spread in time to all localities where water is available and the climate suitable

3 **Main classes of Canals**—Irrigation canals, according to the nature of their supply and system of distribution, are called Permanent or Inundation, but there are many grades of so called Permanent canals from those supplied by unfailing snow fed rivers to others dependent for water on springs or reservoirs. A canal is, however, considered permanent when its source of supply is sufficiently well assured to warrant the construction of a regular fixed graded channel supplied with the masonry works necessary for regulation and distribution. Inundation canals are those dependent for their supply on periodical rises in surface level of the river from which they are taken off—they are rarely fitted with permanent masonry works

The operations described in the following chapters as necessary for an Irrigation Project or Design, are suitable either for a new canal or the remodelling of an existing work.

PERMANENT CANALS

4 **The Project**—When the introduction of canal irrigation into any district, or tract, is considered desirable, it becomes the duty of the Canal Engineer to prepare what is called the "Project" This includes the Plans of the proposed works, the Estimate, a Report enumerating

all points worthy of consideration, and a forecast of the probable yearly expenditure on Works, Maintenance and Repairs, with the anticipated monetary returns.

5. **Financial classification of Canals.**—Under existing Financial rules, canals in India may be divided into three main classes—

(*a*) Productive Works.

(*b*) Protective Works.

(*c*) Provincial or Minor Works.

6. **Productive Works.**—When the forecast referred to in paragraph 4 shows that the net income from the proposed canal will exceed the yearly charges by a sum equivalent to at least 4* per cent. on the Capital invested the work will rank as productive, and can be constructed from borrowed funds advanced by the Government of India, the Province responsible paying the interest charges from the Canal revenues. The forecast should be calculated with great care, and on a moderate estimate of the yearly spread of irrigation to allow for the extreme fluctuations of the Indian climate. A certain number of years is allowed for the development of irrigation after construction has been completed, during which the interest charges accumulate as a simple debit, to be paid off as the revenue gradually increases. On the expiration of the term of years fixed (now 10) † to fulfil the conditions constituting it a productive work, the net revenue receipts should have cleared off all interest accumulated during construction and development.

The Capital account on which interest is paid includes the cost of all preliminary expenses, such as survey, compensation for the land occupied, the cost of the buildings, masonry works and channels, constituting the canal proper, including the maintenance of the above in good order until construction is complete; also the pay, pension and leave charges of the establishment employed, and the value of tools, plant and stock. An item equal to the capitalized value of the revenue derived from the land occupied by the canal, has also to be added, to cover the loss to Government on this account, for in India the State, being the owner of the land, receives a certain proportion of the rental as land revenue. The abovementioned heads of Capital include all the items on which interest is payable; but before any of the revenue becomes available for defraying interest charges, or as a profit on the operations, the following annual liabilities have to be discharged, viz., the cost of Extension and Improvements, not included in the Capital account which have been carried

* Amount is fixed from time to time by the Government.

† *See* paragraph 9, Secretary of State's Despatch No. 1, dated 6th January, 1881.

out during the year, the amount spent on Repairs and Maintenance of the canal when in operation, or running, the pay of all establishment employed both on works and in assessing the revenue, and an additional charge calculated on their pay to provide for their leave and pension allowances

The revenue of the canal is mainly derived from payments made by cultivators and landlords for water actually supplied to crops, receipts from Plantations Navigation and Water power dues, and the above, with a few other petty items, are called Direct Receipts, but the Canal revenue is also credited with a share of that increase in the value of the land due to it being irrigable by the canal, though possibly not actually irrigated during the year—this latter item is called an Indirect Receipt, and is credited to the Canal revenue by an annual book transaction.

From the above brief sketch it will be evident that canals treated as Productive, are worked on strict commercial principles, with this exception, that neither reserve nor depreciation funds are kept up The former is, however scarcely necessary in the case of a great Government, or the latter where the works are kept in efficient order as they generally are, but if the surplus revenue was employed to carry out improvements on the canals instead of being paid into the general revenue of the country, the prosperity of certain of the canals in India would be even more marked than it is at present

7. Protective Works *—Canals when Productive ensure the prosperity of the lands commanded by their waters, without burdening the general revenues of the country it however occasionally becomes expedient to bring canal water into tracts so situated, that the revenue derivable from the works will not pay the interest charges on the Capital invested Under certain conditions the Government of India will advance the necessary Capital from Protective or Famine Funds, but it is not probable that many works of this nature will be taken in hand in the future, unless the Province interested agrees to guarantee the yearly charges In certain cases it may nevertheless be both profitable and judicious for the Province to do this, under the system of Financial Contracts now in force, which renders each Province independent of Imperial control, as far as regards interior finance For example, if we take the case of a district suffering from a fluctuating rainfall, the main

* Protective Public Works have been defined as those which although not directly remunerative to an extent which would justify their inclusion in the class of Productive Public Works, are calculated to guard against a probable future expenditure in relief of the population.

revenue from the district being derived from the land, the partial loss of this revenue even for one year may easily amount to far more than the deficiency of the canal revenue over a series of years; and when it is remembered that the population in India is mostly agricultural, and that a famine necessitates extraordinary expenditure from Government for relief, the advantages of an assured supply of water can scarcely be over-estimated. It may, however, well be asked: Why should not all canals be Productive? One of the principal reasons is that owing to local conditions the supply of water available is frequently so small, compared with the cost of the work necessary to distribute it, that a prohibitive price for water would have to be charged to cultivators to render the canal self-supporting. The rates for irrigation at present charged are low, far too low in the opinion of many experienced Revenue authorities; but to raise them above the average in districts requiring Protective works, would tend probably to deter the farming classes from extending the crop area. Cultivators in India have absolutely no system of self-insurance; so far from putting the profits of a good year against the losses of a bad, their usual custom is to spend all they can make in favourable seasons, and borrow at a ruinous rate of interest when times are hard. Thus it will be easily understood that the maximum uniform rate which can be charged for canal water is its value in years of fair prosperity to all classes, i.e., when grain is cheap and the profits from farming only moderate. It is needless to observe that rates fluctuating with the season are contrary to the principles of good government and the stability of tenures. It should not, however, be taken for granted, that because we have a dry country, and water in the rivers, the construction of Protective canals will necessarily prove profitable, or even advantageous; on the contrary, the case of each work and tract must be taken up and worked out with great care, both from the Revenue and Engineering points of view before a decision can be arrived at.

8. **Provincial or Minor Works.**—Small works, the estimates of which can be sanctioned by the Province or Local Government without reference to the Government of India, are classed as Provincial or Agricultural. The elaborate forecasts necessary for Productive and Protective works are not required for Provincial Projects; but at the same time it is equally expedient that they should be founded on a sound financial and agricultural basis.

9. **Financial aspect of Canal Projects.**—This question of Finance has been touched in here rather out of place, as it, in a measure, marks the difference between the projects usually required from the Canal

Engineer, and those prepared by the other branches of the Public Works Department in India. No direct return is received from the expenditure on Buildings, Roads, or Bridges, and Railways are often constructed for strategic reasons, or as links of a great system, quite independently of their returns from public traffic The Canal projector, on the contrary, has always to consider ways and means, and must often relinquish plans, admirable perhaps in an engineering sense, but unsuitable for construction because a good return for the capital invested cannot be earned

CHAPTER IV.

SELECTION OF SITE FOR HEAD WORKS.

For canals taking out directly from rivers the selection of the best position for the head works demands a close examination of the country, and a thoughtful consideration of all the questions involved, questions not only numerous, but complicated, both in their relative importance to finance and engineering expediency, and their bearing on the general design.

2. **Great divisions of river channels** – Putting out of consideration for the present minor streams rising from springs in low lands, the large rivers of India show four marked divisions of character extending over long stretches of channel, viz. the mountain length with a rocky bed, narrow gorges, and many abrupt falls; the submontane boulder tract, with high slopes, a wide bed divided by islands into several channels, and many hill torrent affluents; the trough portion with a sandy bed, a low slope and a wide khadir bounded by high table-lands; and finally the delta in which length the channel bed is elevated above the general level of the country, which has long gentle transverse slopes on both sides.

3. **Minor divisions.**—That these great divisions can be further sub-divided will be easily understood; indeed, when it has once for all been determined from which of the great divisions the canal will start, the exact location of the head site must be fixed by the special characteristics of the sub-division. These minor sub-divisions may be briefly sketched, thus the boulder tract often runs up far into the hills, and lengths of it may occasionally be met in hill valleys interrupting the continuity of the rocky bed; the slope of the boulder bed may vary from over 100 to sometimes as low as 5 feet per mile, causing naturally great differences in the character of the valley. Beyond the apparent junction of the boulder and sandy beds, boulders will be met with in the subsoil, and for some distance below the junction the sandy bed may be but slightly depressed below the terreplein. The trough length again will present most marked contrasts sometimes—but very seldom, the river will occupy the centre of the khadir in a straight reach with fairly high banks—more usually the river hugs one bank. In this case the other edge under the high bangar is almost invariably traversed by a minor stream or nala which drains the wide stretch of abandoned khadir, and is itself the last remaining trace of an ancient course of the river. There are many

indications to show that the trough lengths of these Indian rivers were deltaic in their nature in past ages and that by a steady retrogression of levels which is still going on, the river bed has been cut back through the table land. The usual abrupt descents from the table land and the general low level of the river valley show, however, that the limits of oscillation of the river bed are at the present time very much the same as they were when this process of retrogression commenced.* This is an important point to bear in mind, as it shows that very little dependence is to be placed on an apparent permanance of existing channels, at the same time great variations will be found in the soils of the valley, and many lengths will be found of a far more permanent nature than others Thus, in some sections soils will be found varying from light deposits covered with a sparse growth of vegetation to mere sandy dunes, whilst in others will be met fairly strong clay stretches well cultivated and drained with long established villages standing on them As a rule the deposits will be of a less permanent nature on one bank, but the distinction will not be so marked between each bank in the same section as between different sections. This variety in the quality of opposite banks is generally caused by the difference in depth of flood water passing over them a deep flood spill, when not a backwater throws down a coarse deposit, while a thin film has nothing but clay to part with. The reasons for the great diversity in the different sections of a trough river are somewhat obscure, as the action of a great river in floods is complicated by a number of conditions with which experience has as yet but partially acquainted us A careful study of any such river in flood will show one peculiarity which throws some light on the subject, viz, that the great mass of the silt contained in the flood water is not carried long distances the flood does not, as might at first be supposed, carry down all the detritus from the hills direct to the plains; on the contrary, the action is one of picking up and depositing again a short distance further on, or to one side—again picking up and depositing, and so on A certain quantity of the finer silts and the clay which is almost dissolved by the flood water is undoubtedly carried great distances and slowly deposited as the steady reduction in slope reduces the velocity, but the great mass of the heavy silt carried by the floods is locally eroded,

*This process of retrogression cannot have materially increased the bed slope of the rivers as the beds are usually more or less parallel to the country surface, though depressed below it. The Ganges for instance, may be fairly assumed as having cut back about 70 feet between Hardwar and Allahabad, a distance of about 400 miles as the crow flies—this only amounts to 0 18 foot per mile.

and again locally deposited from time to time. This peculiarity explains why the deposits forming the valleys are not as uniform in quality as they would be if regularly deposited from floods carrying the detritus from a local source. The original variations in the quality of deposit in different sections are probably due to the natural differences in the soils of the table-land through which the river cut the trough, combined with the reduction in velocity caused by the tortuosity of the trough or channel in extra sandy sections.

The contours of the valley lands in the trough division have an important bearing on the adaptability of different sites for the construction of head works. Section A (*Fig.* 29, *Plate III*) shows a case where the river has deserted the east bank, but probably since a comparatively recent period, for the slow action of successive floods has not yet raised the low valley on the east. Now although, owing possibly to the comparative blocking up of the channels at its head, only a thin spill passes over this low valley in floods; yet as the construction of a weir or bar on the main stream will undoubtedly raise the flood level, there will always be danger of the main stream deserting its existing channel and taking to the east bank again. This danger is enhanced by the well known fact that abnormal floods do occur, though not at frequent intervals; the danger again is, however, greatly reduced by the well known objection trough rivers have to re-occupy from surface spills channels which they have deserted for some time.* When they do change their courses back to some old line, it is generally by side erosion of the banks. The section, however, cannot be considered a favourable head site, and one like that shown in Section B is much to be preferred all other conditions of soil and situation being equal; for the contour as it stands is not only advantageous, but in itself a material proof that for a long time past the river has been pretty constant to its existing channel.

In the trough length the river bed is steadily, though perhaps slowly, being deepened, on the contrary in the delta division it is as surely rising. (*See Fig.* 30, *Plate III.*)

This different tendency is simply due to the gradually reducing slope of the country diminishing the silt-carrying power of the flood water. The delta deposit is more or less clay, though sandy on the actual river bed; as the velocity is then greatest on account of the depth. When the floods are kept within bounds by embankments the bed is very quickly raised, and destructive floods from breaches are certain to ultimately

* Such old channels become lined with a more or less thick coating of clay from slow flood deposit, and the beds are generally covered with heavy grass or jungle

occur When the floods are not confined, the surface of the country generally rises in a gradually decreasing slope from each bank of the river (*see* fig 31 *Plate III*) affording many and great advantages for economical irrigation In such tracts canals serve a double purpose for they not only bring water to the places where it is needed, but they also by taking off a large proportion of the floods save other tracts from inundations where water is not required

4 **Torrents** —The possession of a delta close to its mountain source may be held as the feature distinguishing a torrent from a river or stream The torrent course may, like that of a river, be separated into four main [illegible]

From this marsh small drainages break out in places to unite further down into a defined channel or stream (*see Fig.* 32, *Plate III*) These physical features are marked by one peculiarity, viz, the complete absence of visible water in all the divisions except for a short time during heavy rain. Even the final nala rarely contains any water unless it derives it from some spring unconnected on the surface with the torrent The floods which pass down these torrents are short lived, though extremely violent, and the slope on the fan generally varies from 25 to 15 feet per mile Two successive floods rarely or never occupy exactly the same position on the fan, for coming down loaded with silt they spread out in different directions being constantly forced aside by their own deposits (*see Fig.* 33, *Plate III*)

It will be easily understood that the surface of the water in torrents is not smooth like a river flowing with an established regimen, but a series of waves one following the other at short intervals It is now generally admitted [*see (a) Fig* 33 *Plate III*] that down to a certain limit, the bed in the fan moves with the torrent, and that the surface of the fan after a flood does not by any means represent the actual bed during floods. For constructive or experimental purposes the limit of movement of bed can easily be ascertained for a particular locality, and an observed discharge by simply sinking a pillar of artificially coloured sand in the bed and measuring the limit after a flood Although the contour of the surface of the fan is constantly changing, yet the increase in its actual dimensions [illegible]

which cross the Ganges Canal a short distance below Hardwar. These torrents are carried across the canal in superpassages respectively 196 and 296 feet wide. The Ranipur passage was fixed just below the fan with its floor 3·5 feet below the normal bed of torrent, the slight silt deposit thus caused was many years ago removed with ease by an improvement in the outfall—this, however, did not cause the fan to reach the work. The Pathri passage was fixed within the fan with its floor level with the normal bed; after a time heavy retrogression in the Pathri torrent above the fan took place, the immediate result was a steadily increasing deposit on the floor of the superpassage, and as soon as the retrogression was completed up to and stopped by the hills, the deposit ceased to increase. These superpassages remained in the conditions described for many years, after which the widths of the masonry channels across the canal were considerably reduced, and the channel outfalls below improved, with the result of washing away all the accumulated deposits, and causing extensive retrogression of the beds necessitating artificial protection. The excessively silt-laden nature of the water during floods, therefore, must not be taken as an index of the quantity of detritus brought down by the flood from the hills: the same action that takes place in rivers is exaggerated in torrents, which in their downward course are constantly picking up and re-depositing the same sand a short distance lower down. That this must be the case is at once evident from a consideration of the extreme and constantly diminishing slope of the course and the unstable nature of the bed.

Although somewhat out of place, it is necessary here to draw attention to the results of fixing a hard bar across such torrent beds at different levels [*see* (*b*) and (*c*), *Fig.* 33, *Plate* III]. Now when the bar is fixed as in *Fig.* (*b*) with its crest at or above the normal level of the torrent, the flow of the sandy bed is checked during floods, which has a double effect, viz., it causes the water to rise and fall over the bar giving the flood thus additional scouring power; and it also reduces the velocity upstream, thereby clearing the water above the bar and adding to its eroding capacity below, where the slope is not decreased. The result which invariably follows the imposition of such bars is a marked retrogression below them—this is well exampled by the Nowgong weir on the Eastern Jumna Canal, the Dhanouri dam on the Ganges Canal, and many other works. For years after its construction, the retrogression had increased below the Nowgong weir on a torrent which had a uniform slope of 8 to 9 feet per mile before the weir was constructed. In 1842 the lower bed was 21 feet below the crest, when the weir was breached for 190 feet of its length, and the succeeding floods of that year nearly restored the bed

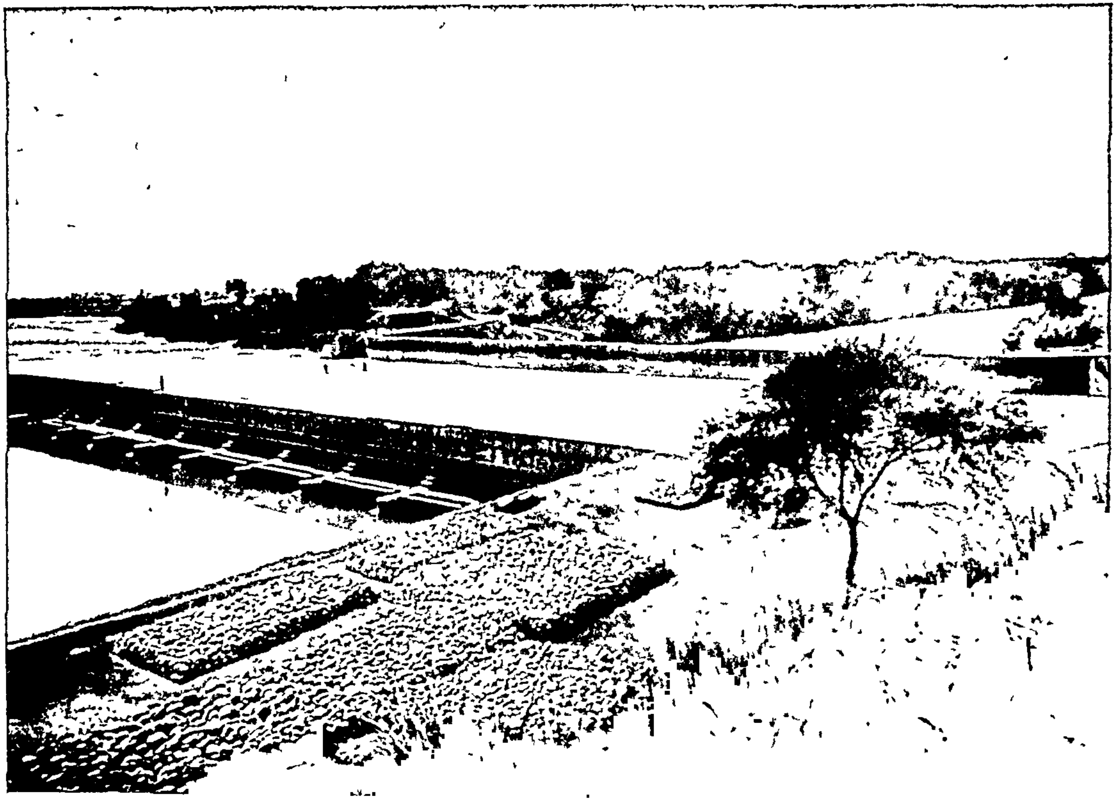


Photo.-Mechl. Dept., Thomason College, Roorkee.

RANIPORE SUPERPASSAGE, GANGES CANAL.

through the breach to its original uniform slope. The bed below the Dhanouri dam has been steadily lowering year by year, and to ensure the safety of the works it has been found necessary to build a series of crib and boulder bars stepping off the slope.

5. Hill streams.—Hill streams derive their supplies from hill springs, sometimes from lakes fed by springs, or lakes which are simply reservoirs of hill rainfall—in the last case the supply must be considered as extremely precarious. In the passage from the foot of the hills to the low lands, a considerable proportion of the supply is absorbed in the soil, and many of the smaller streams entirely disappear a short distance below their sources. In the larger rivers and streams the water thus lost by percolation probably re appears to a certain extent lower down in the channel, but the water from the small streams simply goes to feed the great Bhabar sub-soil reservoirs.*

Canals can be made most profitably from small hill streams and springs with their head works in the hill gorges, but the channels have either to be lined with masonry, to prevent excessive loss from percolation and erosion of the bed from the great velocities engendered by the high slopes, or be given comparatively low slopes and numerous falls, inducing deposits which help to minimize the loss from percolation. The choice of sites for head works is generally limited, but their construction and protection does not present any great difficulty, as an abundance of suitable material is always economically available

Weirs are rarely required to turn the supply into the heads of the canals. as owing to the high slopes temporary boulder bounds are sufficient in the cold and hot weather, and in the rains the height of the floods will usually be considerable—indeed the main difficulty met with is to locate the head so that it will serve in all seasons. This difficulty is best overcome by selecting a site naturally protected by large projecting masses of rock, which, diverting the great rush of the floods, will allow the supply to enter from an eddy or back water. Care must also be taken to ensure that the channel can be led away from the head without interfering to a serious extent with the natural drainage from the hills. Where such drainage crosses the line massive masonry works will be required, as on no account should either floods or *debris* be allowed to enter the channel—the former would almost certainly destroy it, as all hill torrents, though short lived, have a very heavy discharge compared with the area of their collecting basins, and the *debris* would, by choking the channel. cause. an overflow

* *See* Well Irrigation, para. 19, chapter II.

of the supply with a similar result. It may be here mentioned that many of the hill canals in India creep for miles along steep hill sides, where a passage even on foot is found with difficulty; and in channels so admirably protected by arching, superpassages and culverts, that they have become practically independent of the effects of the rainfall, and carry their supplies with a marvellous regularity to the irrigable areas in the plains below.

6. **Spring streams.**—Of spring streams there are two distinct varieties, viz., the small river with a distinctly marked channel from the hills, dry or nearly so near the hills, but gaining steady increments to its supply as it passes through the heavy clay lands below; and the local stream rising from a swamp or nest of dry channels, which gradually accumulates more and more water in its downward course. A river of the first class has generally a tortuous course, a sandy bed, and is subject to severe floods. Its channel sometimes occupies a local watershed, and may indeed be said to be slightly deltaic in its nature, and it differs from the large rivers in not possessing a valley*—this renders the floods more violent in their results and causes them frequently to spread over the surface of the country, and to eventually find their way into the adjoining rivers on either side, thereby often cutting up the *doabs* by cross drainages. It is not an unusual result for the floods of one river to be entirely diverted to another, and on the whole this class of stream must be considered as extremely unstable; and when utilized for canals, the head works require not only careful location, but constant care and attention. They are also very expensive in first cost, as the heavy floods call for relatively larger and more massive works than are required in more stable streams with similar minimum supplies.

In this class of river the fall in the country being rapid, there are few difficulties with regard to leading the supply on to the ground surface it is desired to irrigate. The points to be considered in selecting a site for head works are stability of channel, good soil, and if possible high banks, and as these three conditions more or less depend on one another, they will, if they exist at all, generally be found combined. A naturally straight reach for some distance above and below the site is perhaps the most important of all for the construction of the weir; by reducing the velocity above, it will lessen the tendency of the river to wander, and the fact that such a reach once naturally existed, is proof positive that it can be maintained by properly designed training works; while if a winding reach is selected with the hope of eventually correcting it by straight cuts,

* The floods being as high or higher than the banks, the deposited silt is high also.

etc the very means adopted may produce results neither anticipated nor desired At the same time a certain amount of straightening may be allowed on account of the reduction in slope caused by the elevation of the weir The objections to making alterations in the length of a winding stream are very great in easily eroded soil with high velocities, for owing to the determination all such rivers have to maintain their original length, either the concave curves BB will be constantly eroded and silt deposited at CC (*see Fig* 34, *Plate* III) or the stream having exceeded the length required by its velocity will try to shorten itself by a straight cut through one of the bends or an erosion of some deposited silt – in any case there will be a constant change of position going on which renders such sites unsuitable for permanent works

It is necessary to select positions where the river is confined within high banks as owing to the depth of the floods being relatively great compared with the discharge and the river channel being unstable and liable to wander the flank works invariably require raising above the maximum anticipated high flood level with low banks the protective embankments would be both costly and insecure

If the weir and canal head site are safely situated with reference to floods the canal channel may well be taken along low land gradually leading to the watershed for the expense of providing minor drainage crossings will be less than the cost of deep excavation This course is however only feasible when either the river has a valley and the canal channel can be cheaply protected from floods or where the high river banks form as is generally the case the real watershed In the latter case the channel would first cut through the high bank then pass along a contour outside it gradually regaining the watershed as the slope of bed permits of a command of the country In both cases the local drainage cut off by the canal banks requires full provision for its passage over through or into the canal—the last arrangement being held objectionable if it can be avoided by any other means

The second class of spring stream demands very different treatment, here we have good soil a defined and practically permanent channel with floods wholly dependant on local rainfall The weir may be designed with little hesitation on the basis of the mean capacity of the channel expansion for abnormal rainfall being allowed for by keeping the flank opposite to the canal head at the same level as the river bank As the soil of the river banks is generally hard clay the passage of an occasional flood round the flanks is not dangerous provided the masonry work is carefully protected by pitching so as to prevent erosion in its immediate vicinity

These works are generally small owing to the proximity of the sources of supply, but should be substantially designed, as owing to their being usually situated in somewhat inaccessible localities, they cannot benefit by the frequent inspections of responsible officers to the same degree that larger or more important works do.

Ample provision against retrogression of bed level should never be omitted, for falling as most of these streams do, with a high inclination of bed and a short course, into larger streams they are liable to adopt very quickly every alteration in level of the larger stream, and it has already been noted that the larger hill-fed streams are extremely unstable in character. It may be noted that, in order to obtain the full supply from these streams, a series of works will be found necessary, as the springs are not confined to one locality, but appear at intervals over a considerable length of channel.

7. **Great river Head works.**—The decision whether the head works of any canal should be situated in the hill boulder tract, or in the sandy trough, must be determined by the position and level of the country which requires irrigation. There have been warm controversies at various times between experienced Canal Engineers regarding the relative advantages of both positions, but the practicability of both classes of site having been demonstrated by actual construction, it is quite evident that at the present time the area to be commanded must determine the selection, unless great excess of cost should render one of the sites a financial impossibility.

There are, however, on general grounds, four strong arguments in favour of the trough site—*First*, the well known fact, that a dam in the boulder tract, even when it is to all appearance perfectly water-tight does not hold up all the water in the river, for there is always a strong sub-soil flow which appears lower down, and which combined with percolation from the bangar, and possibly a supply from some affluents, will give an increased discharge at the trough site. *Secondly*, in the Bhabur reach a canal from boulder head works is certain to lose a large proportion of its supply from percolation, and this loss may be greatly increased if the channel passes through light sand also, as it is almost certain to, before it reaches the firm soil of the *doab*. *Thirdly*, the tracts lying at a short distance from the hills rarely require water with the same urgency as those lower down, and what quantity they do want can generally be given by petty works from minor hill or spring streams; at the same time it is bad policy in a financial point of view to entirely ignore these upland tracts, for growing as they do high class crops, such as rice, sugarcane and wheat, they are very

important to the country *Fourthly* the certainty of getting a supply into the canal at any moment when required which is ensured by a masonry weir fitted with proper regulating arrangements This argument it somewhat neutralised by the fact that up to the present time the boul der head works in the north of India have never yet been known to fail —it must be admitted however as a possible contingency *

As far as regards the relative expense of construction it is impossible to draw any comparison without a sufficient knowledge of the details of each case, but it may generally be assumed that the trough weir will be the most expensive to construct. It was formerly anticipated that the annual expense of maintenance would be greatest on the boulder class of head works, for these not only require annual re-construction, but the ex pense of maintaining the torrent and other drainage works crossing the channel in its upper reaches must justly be taken into account. but experience has proved this anticipation a fallacy and a heavy annual expenditure on training works must be considered a necessity for all great trough weirs—this at least as far as existing experience goes—for there are reasons to believe that experience in the management of these works will tend to reduce this great expense When estimating the maintenance of such a great and important work it must be remembered that the sense of heavy responsibility on the Engineer in charge will not allow him to risk an accident, even if it appears remote and that he will be quite justified in spending large sums on purely protective works

It may occasionally be found judicious to construct both classes of head works for the same canal, particularly if few difficulties are anticipated in the course of the upper channel. The boulder head would in this case be first constructed to supply the submontane tracts and earn an income for the canal before the heavy expense of the trough weir was undertaken It is probable that a slight increase in the total supply obtainable from the

* NOTE.—The temporary boulder bunds put up every year after the rains may never fail entirely, but frequently they are too late to suit requirements when there is but little rain in August and practically none in September the demand in September for rice and sugarcane is intense in October there is added a demand for *paleo* for wheat As the temporary bunds are not started till about the 1st October and are not finished before the 15th November the supplies in canal are far below requirements during September and October

The Upper Ganges Canal was badly hit two years in succession with a failure of the monsoon in the months of August and September considerable damage being done both to rice and sugarcane and the water available for *paleo* for *rabi* being inadequate and late To avoid those losses in the future, Permanent Head Works are now under construction a little above Hardwar

river would result by following this course, as the percolation from the high lands is increased by every foot of reduction in the water level of the river, and some discharge from the boulder head supply will be caught up for use a second time.

8. **Choice of boulder Head Works.**—The main points to be kept in view when choosing a boulder head site are the selection of an improvable side channel,* not directly subject to excessive flood action, into which the cold weather stream can be easily diverted from the main channel, and the attainment by the canal channel of the backbone of the country without serious interference with cross drainage. The question of boulder heads therefore naturally divides itself into two parts, viz., the river works and the canal channel, from its head to the point at which it emerges fairly into the *doab* on the watershed.

9. **River works.**—It need hardly be stated that the side or supply channel mentioned in paragraph 88 should lead directly on to the point fixed on for the head of the excavated channel. This supply channel itself will probably need adjustment of levels and bed to suit the supply required for the canal. The canal supply could not with safety be taken from the main river directly, unless very massive works were provided, and even these would not provide against the contingency of the head being heavily shingled up; while the supply channel, being capable of disposing of a fair share of flood water, and being more or less under control by means of waste dams, is easily kept open at all seasons.

This control over the supply channel is maintained by making its bed slope after the first few furlongs something less than that of the main river. The actual difference to be made must be determined by local conditions, but a total rise of 5 to 8 feet at the canal head will nearly always be ample—there will rarely be difficulty in gaining this rise owing to the high slopes of the boulder bed. (*Fig.* 35, *Plate* III.)

It will be seen from the diagram that the floods of the main river cannot easily break into the supply channel except at the entrance (which should be well protected), and that the excess water in the supply channel can easily be passed over waste weirs or through dams into the main river from the tail or convenient points above it; this rise in level will also reduce the depth of excavation of canal channel at its entry into the high bank. It has been previously noted that the bed of rivers in the boulder tract is rarely confined to one channel. *Fig.* 36, *Plate* III., gives a common disposition of the channels which are usually separated by islands covered with a thin layer of mould, and often wooded.

* Called the supply channel.

These channels might easily at first sight be supposed very unstable—this, however, is not the case Changes in them though constantly occurring, are gradual and slow, except as the result of a great flood or some artificial interference with nature, and although the experienced observer will readily detect the signs of channels deepening or shingling up yet it requires very careful engineering and often considerable expenditure to promote any desired change in the regimen of such a channel.

On the diagram (*Fig* 36) have been shown the usual bunds* and dams which would be necessary to turn the cold weather supply into a canal The bund A over a shallow channel would easily be made water tight B over the main stream would probably leak, as all these bunds, being temporary and intended to last for the cold weather only are made of cribs filled with boulders or boulders only faced with shingle, a supplementary bund C and cut are therefore provided to catch the leakage In very large rivers with deep beds a series of such bunds and cuts may be required—, the slope of channel being great the level of water headed up on each successive bund is reduced (*Fig* 37 *Plate* III)

It is to allow for this series of bunds that the slope of the upper reach of the supply channel is not reduced It may even be found necessary to give it a greater slope than the main river for a short distance or to hold up the level of the main stream bed, by a sunk masonry or crib bar to prevent retrogression of bed or local deep scour, at the same time *great care should be taken not to induce too strong a draw into the supply channel during floods* Indeed it is a wise precaution to protect the entrances with bed bars and powerful revetments Beyond the above, regulating arrangements at the entrance of the supply channel are rarely either necessary or expedient The point D will generally require strengthening, and the opposite bank of the river rivetting, but the main principle to be kept in view is simply to maintain an open head of fixed dimensions and to pass off the excess flood supply back into the river by the tail dam aided if necessary, by the spill over a waste weir some distance above this dam.

The logitudinal section of the bed of the main river below D, the head of the supply channel requires examination, as all rivers in the boulder tract run in a succession of pools connected by rapids For a favourable site, the rapid below D should leave ample room above it for the supplementary bunds It need hardly be said that the condition of this rapid should be verified year by year after the floods in order to check any tendency the river may show to alter or move it.

* Bund = an earthen or boulder embankment

The detail of the bunds, their construction, removal during floods, and the usual arrangements for controlling the river and preventing cross drainage by embankments, are referred to in the descriptions of works.

10. **The upper reaches of canal channel.**—The extraordinary variations in the disposition of the drainage from hill tracts render it impossible to lay down any fixed rules for the alignment of a main canal from boulder head works. A sketch of the practice usually followed will, however, sufficiently indicate the principles by which Engineers in India are guided.

It is first necessary to note that the watershed or backbone of the country between any two great rivers does not of necessity lie midway between them; on the contrary, it usually lies very much closer to one than the other, so that a cross section of the country would show levels something like *Fig* 38, *Plate* III.

The drainage naturally follows the slope of the country, so each river will receive as a rule many more affluents on one bank than the other.

Now the desired object is from the dam to gain the point A or A′ (*Fig.* 39, *Plate* III) where irrigation should commence, with the minimum expense and the maximum safety for the future maintenance of the works. This end may be attained either by boldly striking across the courses of the torrents in more or less deep excavation, *vide* A, or by following low ground or the channels of existing minor branches of the main river or other streams to gain command of the country lower down by a circuitous route, *vide* A′.

The objections to the first course are: *heavy expense of construction, probable increase in loss of supply from percolation* and the *necessity of providing full waterway for the greatest possible discharge of torrents near the hills* where the rainfall is often excessive, and the floods are both sudden and violent in their effects. Its advantages are: the *ensured permanence of the supply* in all seasons, *facilities for inspection and regulation* and the *protection of the country from the injurious effects of floods* artificially carried in channels not originally intended to transmit them.

The objections to the second course are: *loss of head*, i.e., in most cases it will not be possible to command the main watershed as far up country as is agriculturally desirable, *injury to the adjoining country from unregulated floods and saturation of low lands* for, passing through depressed clay and sandy tracts, often in embankment, the supply in the canal will raise this subsoil water level, already high, to the surface of the ground, and although this itself in time will check the loss of supply by filling up the avenues of percolation, yet the injury to the country in

health and loss of culturable areas thus caused will be great, *expense of maintenance*, *instability of the canal supply* which is liable at any great flood to be interrupted and as floods from the hills and rain in the *doabs* do not always occur at the same time the interruption may often be a serious disaster, and *the difficulty of maintaining communication* for navigation will be clearly impossible, and when floods are passing the temporary roads and passages over the diversion works will be blocked The advantages are *economy in construction and gain in supply* due to the springs of the minor streams being diverted into the canal and the power which this course gives the Engineer of first quickly delivering the canal supply by means of temporary works which he can again years after make permanent or improve on the basis of the knowledge gained by observing the force and effects of successive floods

It may be here noted that this latter course of construction was the one invariably followed by the Indian Engineers who previous to the English rules carried out many remarkable canal works in Northern India Their object was however not usually the command of a large area from the main watershed but rather the irrigation of local tracts or the water supply to a great city, and they consequently carried the system throughout nearly the whole length of their canals

These works were not run continuously for long periods under Indian rule their maintenance being dependent on the will of sovereigns whose attention was generally more directed to the aggrandisement of their territories by war, than to the gradual improvements of agricultural enterprise The English Government shortly after acquiring the Northern Provinces of India re-opened some of these canals as their first irrigation works and ran regular supplies in them The saturation and deterioration of soil noted as objections to this course of construction soon however became pressing questions and although the channels have been in a great measure remodelled and many of the evils complained of removed yet it must always be a matter of regret that sufficient funds and knowledge were not at first available to have constructed them originally on proper lines

The damage caused by over-saturation is usually confined to the clay soils and the low valleys of the rivers—it naturally does not occur in the boulder or shingle tracts—and when the levels suit the canal line may with advantage be carried for some distance in the latter class of soil as the high slope which can be given will save great expense in masonry falls The disposal of the cross drainage will require careful management Minor streams can with advantage be taken into the main channel

by inlets, to be collectively passed out at convenient points; but large torrents should be dealt with in detail, as the danger is always present of several being in high flood at the same time. Temporary works, constructed of timber crib-work filled with dry stone, will often be found most suitable for these adjusted natural channels, until at all events experience has shown the nature and capacity of the permanent works necessary to ensure continuous supplies. Under no circumstances should a thoroughly sound and substantial canal head regulator be omitted. This fitted with an escape into some river of considerable capacity, should be situated below the crossing of all torrents or heavy cross drainage, with the intention of effectually preventing floods from entering on the cultivated and more settled tracts which it is proposed to irrigate.

When it is determined to attain the main watershed by a permanent line, the examination of the intervening drainage which has to be crossed must be most minute, and will require a detail chart of levels not more than 1,000 feet apart covering the whole area between the foot of the hills, and the main river. In addition to this, the collecting basins of the torrents rising in the hills should be demarcated and their discharges calculated on the best data available. This extreme accuracy of estimation may not be possible for the project, but even for the preliminary line a near guess at the nature and discharge of the drainage lines is necessary to allow of the selection of an alignment suitable to the class and dimension of work required for each particular torrent.

There are five different methods of passing drainage, viz. :—

Aqueducts—taking	the canal	over	the torrent.		
Superpassages	„	„ torrent	„	„	canal.
Syhons	„	„	„ under	„	„
Inlets	„	„	„ into	„	„
Level crossings		„	„ through		„

Of all these works aqueducts are the safest engineering expedients, but it is not always possible to gain the requisite headway without long and high embankments. Superpassages afford the only possible means of dealing with torrents in the fan stage, i.e., when they are carrying hill detritus in large quantity; they are, however, very liable to be obliterated by the deposits, and the crossing of torrents in this stage should only be attempted as a last resource. Before fixing the level of the floor of the superpassage, the depth of the bed moved by floods should be ascertained, and the levels of the torrent bed above the crossing examined to see if any marked retrogression is in progress or not. If the bed is rapidly cutting back, or shows signs that this will be a probable result of the proposed work, it may be taken for granted that the fan will advance in time, and

the bed level will rise at the site of the proposed crossing—this will involve great danger to the canal and expensive remedies

It will thus be best if possible to cross torrents lower down below the fan where the drainage has entered on the trough stage, in such a position the superpassage is an admirable and safe work requiring few annual repairs and little or no supervision

Syphons are very expensive works compared with the discharge they can dispose of they have also little expansive power and are very liable to be choked with floating *debris* or silt, they however require few repairs little supervision and allow of fairly large range of level between the canal and torrent bed and are therefore useful works for small drainages with well known discharges of moderately clean water In large canals syphons are rarely constructed as drainages suitable to them can generally be taken with safety into the main canal, in inlets the excess supply thus carried in the canal being again taken off lower down at the nearest escape. To avoid flooding the cills of inlets should not be lower than the level of canal full supply The level crossing is simply an inlet and outlet and can be used in positions where the torrent bed either naturally is, or can safely be adjusted to the same level as the canal bed It may be thought an easy matter with high slopes to allow the torrent to drop over a waste weir or fall into the canal and again to run the flood out at the level of the canal bed, but this apparently simple expedient is not suited to torrents carrying large quantities of silt as the first two or three floods would restore the natural slope of the torrent bed thus blocking and obliterating the canal channel

It will be seen from the foregoing remarks that the selection of the alignment for the permanent channel is beset with difficulties The Engineer must steer a middle course avoiding close proximity to the hills as well as the low and swampy khadir land, for a circuitous route in moderate digging, if carried close by the foot of the hills will cross the torrents in their most dangerous stage and be liable to flooding and interruption of communications and will be a worse line than even a long embankment over a wide valley again the best line in other points may be impracticable owing to the levels at which it crosses the torrents

In the case of a very large canal the difficulties are increased by the necessity that exists of keeping the line fairly straight and direct Sharp curves with a large supply would require special and expensive protection and a long line would in any case be very costly Probably the best procedure is to select a good crossing of each torrent separately within certain limits, and then to fit in the canal line by tentative alterations

A careful adjustment of the position and height of the masonry fall or steps for getting over excessive declivity in the canal bed, will afterwards enable the requisite level or headway at the torrent *crossings* to be attained.

11. **Trough Head works.**—For head works starting from a weir in the sandy bed of a river in the trough stage, the main requisites may be briefly described as—*first*, a narrow, straight well-defined river channel with banks not submerged by the highest floods; *secondly* a canal line capable of attaining command of the irrigable area, with the necessary slope by moderate digging; and *thirdly*, the presence near at hand of sufficient material for construction.

The absence of material such as clay for bricks, stone for building and lime, timber, etc can be got over by the provision of a railway—the expense of long transport is, however, a serious item. Inferior sites for the weir can be improved and rendered safe by training works, but no expedient will thoroughly correct a radically bad canal channel line if carried far along the khadir : it will always be open to attacks from the river, rendering "a solution of continuity" possible and most expensive training works over long distances a necessity; moreover, the evils of over-saturation and deterioration of soil will be severely felt and found difficult to cure. If aligned again in deep digging for a great length, the initial cost of construction will be enormous and repairs heavy, as the alignment must be more or less straight, the expenditure on the adjustment of drainage which it cannot curve to avoid will be no light item. Of the two courses the deep channel is probably the best in the long run, as it certainly is the safest, and before all Public works, the irrigating canal, on which depends the agricultural prosperity of vast tracts, should be rendered safe and secure from accidents likely to interrupt the permanence of the supply.

The main guide to the selection of the weir site must, therefore, clearly be the levels of the river cold weather surface compared with those of the point at which irrigation should commence, up to which latter point it is presumed the watershed alignment has been carried from the tail of the *doab*.

A mere inspection of the map, and rough calculation of slope, will show the lowest point on the river which making allowance for the height of weir, has the required minimum level, and from this point up, the river should be examined for suitable weir sites. Now it has been previously noted that the main watershed of the country frequently lies quite close to one bank of the river, and if it is from this bank that the

canal is being projected the difficulties of avoiding deep cutting will be much increased, but as a set-off it is probable that less intercepting drainage will require disposal—whatever is met be it great or small in quantity must be provided for on the most liberal scale and as the trough stage of most rivers is far removed from the hills there will be few difficulties in estimating the maximum discharges Moreover, these drainages not being in any sense torrents can be safely carried by works less massive and particular in design than those required for an impetuous flood

The search for suitable weir sites must be combined with trial or inspection longitudinal sections of the various proposed alignments joining the site with the irrigating point in order to test the relative depths of the excavation necessary for the channels It must not be assumed that the shortest line is always the best With the enormous channels required for large canals the cost of excavation increases greatly with the depth, this is not only due to the extra lead and lift but to the necessity of providing for berms in very deep cuts and to the difficulty of disposing of the vast masses of spoil, and it may often be advantageous in many ways to select a long line in moderate digging with an increase in the actual quantity of earthwork

The examination of the drainage crossed should be thorough and complete including the demarcation of the collecting basin of each drainage line the level of bed high and low water marks soils and registered rainfall, in fact the projector of the alignment should provide the designer of the works with all the information necessary for his calculations

Little more need be said about the actual selection of the weir site A naturally straight reach is a great desideratum for it may be taken as an axiom that if a river is artificially straightened in one place it will curve somewhere else the correction therefore of an inferior site will certainly lead to expensive training works in the future * A naturally permanent site as regards the khadir channel should also be looked for, such sites exist in nearly all rivers on account of the variation in soils for a very slight increase in the power of resisting erosion or some advantageous disposition of cross section will protect a length of channel from change in a river subjected to an unvarying routine of floods of nearly similar maximum intensity

A reconnaissance of the bank of the river will probably show old abandoned reaches which may be profitably utilized to reduce the cost of

* Allowance may be made for the reduction in river bed slopes due to the interposition of the weir which will allow of a certain amount of straightening

excavation of the main canal, particularly when as so often occurs, they are of considerable antiquity, with their beds high above recent maximum flood level; this may easily be the case as the beds of all trough rivers are undergoing slow retrogression. A favourable bend of this nature in the table-land may, if used with discretion, bring the digging of the canal for the first two or three miles within very manageable limits, and with perfect safety to the maintenance of the works. Such bends are frequently found above and below stable reaches of the river, with a projecting bluff intervening—indeed such a disposition of the table-land may be taken as a fair indication of a stable site.

The alignment will be a good one if the canal tends away from the existing river at a right or very obtuse angle, and if the table-land has a gentle slope to the valley. If the canal runs for any distance nearly parallel to the river with an abrupt table-land, there will always be considerable danger of the river cutting it away.

12. **Reservoir Dams.**—Reservoir dams cannot be constructed with safety in either the trough or boulder reaches of a river. In the trough stage the cost of the protection below a high dam would be excessive, and the reservoir itself would in time become a pestilential swamp—the harbour of wild animals and the ruin of the surrounding country. Some of the most naturally favoured districts of North-West India were in times long past thus depopulated under Indian rule by the indiscriminate damming up of the rivers, and it has taken years of painstaking expenditure to even partially restore them to their original healthy condition.

In the boulder stage the cost of the works would be less, but owing to the high slope of the country, except where the contours were extremely favourable, the quantity of water which could be ponded up by a dam of reasonable dimensions would be very small, and what there was would be rapidly absorbed by the porous subsoil.

There are, however, many parts of India where such dams can be constructed with both ease and great advantage to the prosperity and even health of the country; but as a general rule, such works are found so expensive to construct and maintain, compared with the direct profits derivable from them, that they must be considered either luxuries, or only built when without them the cultivating population could not remain in their holdings.

The most suitable country for reservoir dams is one cut up by low rocky hills, with intervening valleys; the gorges between the hills being closed, the valley becomes a natural reservior, and if the drainage line is

followed up step by step through successive gorges, a large supply of water can be accumulated to be drawn off as required. In many parts of India under Indian rule magnificent works of this nature were constructed, many of which remain to this day, others dismantled and breached await that prosperous period of the British rule which will allow of public funds being expended on works not directly remunerative A few of the most favourable have been repaired and some new works constructed in recent years notably the protective canals in Bundelkhand and Mirzapur in the United Provinces

Reservoir dams are only useful in tracts where the rainfall is scanty and insufficient for cultivation The dams should only be of sufficient height to maintain a moderate depth in the reservoirs and as the country, from its contour must have excellent natural drainage no evils from over saturation need be dreaded Indeed in many of the reservoirs now existing the cultivators are well enough satisfied if the rainfall is sufficient to allow of their cultivating the bed of the very reservoir itself after the ponded up water has irrigated a small area below it

Channels from these reservoirs are advantageous only when the volume impounded is large, when the quantity of water is small it would appear more economical to draw off the supply by wells through the subsoil

The selection of sites for reservoir dams is a simple enough matter, in all cases rock of good quality close at hand is a necessity, for it would be impossible to economically carry for any distances the large mass of material required when the feeding drainage is expected to deliver a large supply in the rains The foundations should also be selected in rock and as the hydraulic pressure on a high dam will be considerable, density and freedom from fissures in the natural bed are essential For very large flood discharges wide sites are preferable to narrow gorges, in order that the depth of water passing over the waste weirs may be kept low *As noted above a series of moderately high weirs will generally be found more satisfactory than one very lofty work for the floods in tracts of high slope being usually of short duration, a succession of reservoirs will act as governors of the discharge reducing its intensity*

Flank embankments are dangerous adjuncts to reservoir dams, a site not possessing naturally high flanks and liable to allow the dam to be turned should therefore be rejected even though other respects

Reservoir dams of considerable height have been used as the head works of perennial canals when the river supply was liable to fail in the hot dry season of the year. The reserve of water is no doubt useful, it may almost be said indispensable; but the cost of gaining and maintaining such a reserve is very great, and can only be undertaken in special cases. Such dams have, however, the advantage in an engineering sense of acting as regulators on the severity of floods.

13. **General observations necessary for all sites.**—The following observations should be made for all head work sites, viz.—

Special survey, on a scale of 12 inches to the mile, showing in the minutest detail, the topographical features of the sites, with numerous levels to indicate the elevations

Special cross section of the actual weir site, showing depths at every 10 feet or less, and the nature of the subsoil, with saturation, cold weather and flood levels. The borings to determine the nature of the subsoil should be continued for some distance above and below the actual site selected for the weir the results being indicated on the special survey.

Water gauges should be established at or near the actual weir site on the river bank, and at a certain fixed distance above and below, say 500 to 1,000 feet; the readings of these gauges require daily record at fixed hours, besides which they should be specially read on the occurrence of floods. The upper and lower gauges will give the falls in water surface, data necessary for the calculation of discharges.

It is convenient to plot the readings on section paper as a diagram, so as to show graphically the variations in water surface level, and on the same sheet with advantage may be shown the mean daily rainfall of the collecting area of the river.

Rain gauges are required at a few selected points in the collecting basin of the river.

Discharges showing the maximum and minimum volume passed by the river are most necessary—the latter to limit the capacity of the canal, and the former to determine the magnitude of the head works. It is much more difficult to determine the lower discharge ever passed by a river than the highest. The destruction caused by great floods lives in the memories of the inhabitants, while unless the supply has been previously used for irrigation or industrial purposes, an abnormally low discharge would probably not be considered of much moment, nor without gauges would it be easy for an unscientific observer to mark the reduction in rivers with beds subject to constant change.

Fig 30.

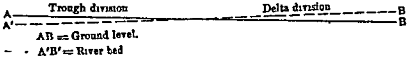


Fig. 31

Fig 33

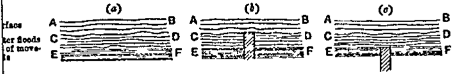


Fig 35

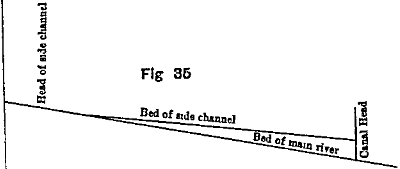
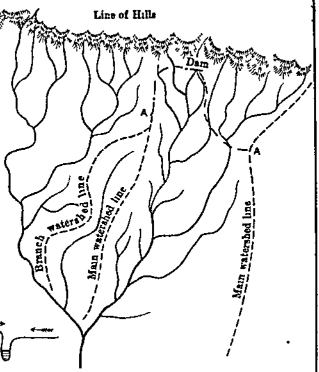


Fig 39



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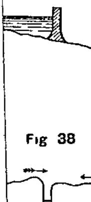

Fig 38

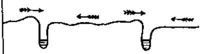

Photo Zinco June, 1924

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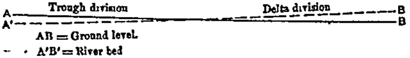

Fig. 31.

Fig. 33.

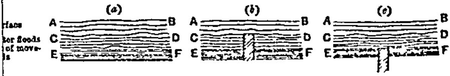

Fig. 35.

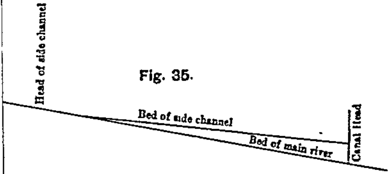

Fig. 39.

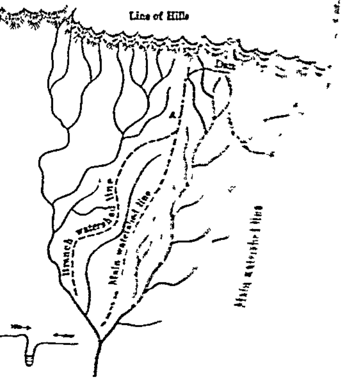

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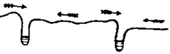
Fig 38



CHAPTER V.

CHANNELS.

1. Longitudinal Sections.—On the completion of field work the surveys and plans should be carefully examined and registered, and all defects and omissions being made good, the plotting of longitudinal sections of proposed channels can be proceeded with. If the distributaries have not previously been named, this should now be done; channels are usually designated after large towns near which they pass: it is, however, judicious to select names easily remembered and of few syllables.

The smallest scale on which the readings of the permanent lines at every 100 feet can be clearly entered on working sections is 8 inches to the mile horizontal, and one inch to 10 feet vertical. Cross sections are rarely required except for the main canal in very sidelong ground, or in other special situations; where necessary they are best plotted on a natural scale, i.e., equal for vertical and horizontal measurements.

Longitudinal sections can be plotted on mounted paper 12 inches wide, which can be procured in rolls of any length: a separate roll is required for each channel, with the name of channel and register number printed outside as well as inside on both ends—a type form of section is given in *Plate* V. This shows all the *information required for construction for* earthwork calculation, and for the width of permanent land. The positions and register numbers of works, outlets and the discharges of the channel at different points are also given.

2. Lowslopes.—The inclination to be given to the channel depends on its proposed discharge, the soil, and the natural slope of the country. In many parts of India the fall of the ground surface is very slight, as low as 4 to 6 inches per mile. It is essential to keep the level of the water in the channel at or near the ground surface, and as the velocity given by such low falls is scarcely sufficient to keep any earthen channel free from silt deposits or weeds, it is evident that in very flat *doabs* the slope of the ground surface determines and limits the inclination of the bed of the channel; in such cases the depth of the supply should be made as great as possible, in order to obtain the highest available velocity.*

3. Lined channels.—Up to the present, except just under the hills, channels lined with masonry or concrete have not been extensively used in

**See* also Punjab Irrigation Branch paper No. 7.

India for the conveyance of canal water it is probable that their introduction on a large scale will shortly follow the steadily increasing demand for economy in distribution but as far as concerns existing practice, it is only necessary to consider the case of earthen channels in fair working order.

4 **Discharge at different points** —The best and most economical section for an earthen channel is now admitted to be a flat trapezoid, and as the velocity of discharge increases rapidly with the depth and amount of discharge, an inclination suitable to an average distributary discharging say 100 cusecs with a depth of 4 feet, would cause disastrous erosion of the bed of a large canal with 8,000 cubic feet discharge and a depth of 9 feet. If the inclination of bed in both cases was 0·3 foot per 1,000, the velocities would be 1·9 feet per second for the distributary, against 4·2 in the canal It is, therefore, clearly necessary to determine the quantities of water required at each point before laying down the channel slopes.

5 **Ordinary soils** —The soils of Northern India vary greatly in their capacity for resistance to erosion by moving water Near the foot of the hills the soil is formed of boulders mixed with gravel and sand, which lower down the *doabs* gradually merges into alluvium composed of all classes of deposit from compact clay to coarse sand, formations of nodular and compact limestone (kankar) are also met with, and in some parts a peculiar black deposit, supposed to be decomposed volcanic ash, called locally *mar* and *kabar*.

6 **Velocities suitable to ordinary soils** —A list of the mean velocities commonly accepted as adapted to different classes of soils is given below In practice a higher velocity may be given with safety to a small channel, for not only has a small body of water less scouring power than a large one, but in the former case, the remedies to excessive slope are inexpensive and the channel of a small distributary being often dry acquires a coating of grass on the silt which increases its capacity to resist erosin

Class of soil.	Mean velocity which will not cause erosion.
Large boulders	20 to 25 feet per second in river beds
Small „	8 to 15 „ „ „ „ „
Single,	5 to 7 „ „ „ if without much sand
Nodular kankar	5 to 10 „ „ „ „ according to compactness
Compact clay	4 to 5 „ „ „ „
Loam	2 5 to 3 5 „ „ „ „
Coarse sand	1 5 to 2 0 „ „ „
Fine sand	1 to 1 5 „ „ „ „
Mar, kabar	1 to 0 5 „ „ „ „

7. **Mar soil.**—*Mar* and *kabar* soil are hard like clay; when dry they form layers 2 to 8 feet thick overlying ordinary culturable or gravelly soil, and their contraction when drying after the rains is so great as to cause fissures several inches in width and of great length and depth. Indeed the surface of a *mar* tract is often so reticulated with cracks in the dry season as to render riding over it a matter of considerable difficulty. When wet, *mar* soil becomes so soft and spongy that even walking on it on foot is almost impracticable. *Mar* and *kabar* soils are consequently unsuited for canal construction, and there is also some doubt as to their fitness for irrigation. The results of the Betwa Canal, recently constructed in Bundelkhand, which has channels passing through these soils, must therefore be looked for with interest. If the great difficulties connected with the maintenance of the distributary banks, and the distribution of water can be overcome, the profits to the agriculturists should be great, as these soils are marvellously fertile; the demand for water for such soils will, however, always be fluctuating, as when the fall in the rainy season is up to the average, no further watering is required to bring the *rabi*, the principal crop grown upon them, to maturity. Indeed in such years, cold weather rain, the salvation of crops in other soils, is frequently considered a positive injury to *mar* wheat. The thickness of the *mar* stratum being often slight, it has been found in practice sometimes economical to remove it and make the channel out of the underlying soil.*

8. **Ordinary safe velocity.**—As far as distributaries are concerned, sandy soils, as before remarked, ought to be avoided as unsuitable for irrigation, and the certain cause of loss of water by percolation. Kankar and clay strata will rarely be met with continuous for a long distance, and it will, therefore, be generally safe to accept the slope giving a 2·5 to 3 feet per second velocity. When the ground surface fall is sufficient, excess slope in the ground surface can be disposed of in masonry falls.

9. **Disturbing influences.**—It should be distinctly understood that the ultimate velocity in the distributary will be that corresponding to the surface inclination of the supply, and that the results of the slope given

*NOTE.—Sugarcane and rice were tried in *mar* soil and have given fairly satisfactory results and the areas *under these crops are increasing.* By keeping distributaries running during the rains, the banks are kept moist and so fissures are avoided and silt linings for the channels obtained, helping to make them more watertight

The Betwa Canal and the more recent Ken and Dhasan Canals have amply proved their usefulness as protective works: with an extension of area under sugarcane and rice they may eventually earn sufficient revenue to cover interest charges on the capital expenditure.

to the bed may be greatly modified by other works—the effects of the withdrawal of water for irrigation of silt and weeds

10 **Silt deposits** —It is difficult, if not impossible, to say what velocity is sufficient to prevent silt deposits or the growth of weeds As a rule weeds owing to want of light, will not grow in silt laden water, and as the quantity of silt carried by the supply varies with the river from which the canal is taken, the season of the year, and the velocity of the main canal itself, it is clear that no given slope suitable to ordinary soil and the obligations of distribution will meet all the required conditions On the older canals the velocities in the main channels considerably exceeded those of the branches, and as water moving at a high velocity can carry more silt than water travelling slowly, a deposit was thrown down at the heads and in the upper reaches of the distributaries The minor heads, moreover, being generally taken out at right angles to the major, caused an additional check to the current which probably increased the deposits The frequent removals of this silt to restore the original slope resulted in high mounds of sand along the banks, and necessitated both heavy expenditure and inconvenient closures It was eventually found after close observation that the redeposition of the silt, followed the clearances very quickly, after which the channel appeared to attain a regimen of its own, and little or no more silt was deposited, the discharge being only slightly reduced, owing to the increase in velocity, consequent on the increase in slope caused by the deposit It is not quite clear why the silt deposit did not continue lower down the distributary where the original slopes remained unchanged The most probable explanation is that silt laden water is peculiarly susceptible to a sudden change in velocity, and this view is supported by the results of observations on river shoals

The inclination finally given to the beds of these old distributaries was one with a rapid fall near the heads gradually merging into their original slopes, and at the same time the velocities in the main canal were reduced by raising existing falls, building new ones, and fixing bars across the bed. This also gave the increase in level necessary to restore the original supply to the raised distributary heads—the results of this procedure were satisfactory, and should be borne in mind when dealing with similar cases in new projects.

Where there is no sudden change in velocity, and the amount of silt carried is not excessive 2 5 to 3 feet per second is generally sufficient to prevent deposit, and also the growth to any injurious extent of most of the weeds common to warm climates.

11. Notched Falls.—Of course when possible the slope chosen for a distributary or canal should be the actual slope of the country it traverses, but for many reasons this is not often possible; sometimes the actual slope would be too great, and it is but seldom sufficiently regular. Thus it happens that a canal is usually divided into reaches or lengths throughout each of which the channel section and slope are constant, the passage of the discharge from one reach to the next taking place over a fall by means of which the height of the water level relatively to the surrounding country is kept within convenient limits.

The proper design of these falls is attended with a certain amount of difficulty, and the correct form of fall is known as a notched fall. The difficulty primarily arises in the following manner, though it is complicated by further considerations. The discharge of the canal is a variable quantity depending upon the amount of water required at the time; thus the depth of water in the reach above any given fall is not constant, and if the fall be just a simple weir able to pass the discharge corresponding to a given depth in the upper reach, then it will be found that for other values of the depth in the upper reach the discharge over the weir with the new value of the depth will no longer be the actual discharge of the upper reach, but will be either too great or too small, and consequently the surface of the water just above the fall will either slope down or slope up, so causing the discharge over the weir to equal the actual discharge of the upper reach. Now it is of importance to avoid this variable sloping of the water surface, because, in addition to injurious effects upon the channel bed, it alters the heads at the off-takes of the distributaries, which are usually situated in the immediate up-stream neighbourhood of a fall, and thus causes undesirable fluctuations in the values of their discharges.

It is impossible here to enter fully into the theory of the design of notched falls, but we will indicate the general principles upon which such design is carried out. For further details the students should refer to the note on Notched Falls by A. G. Reid, Esq., Punjab Irrigation Branch Papers, No. 2, issued by the Punjab Government.

Supposing for the moment that the problem was merely the determination of the form of notch required to pass every discharge of the upper reach with the depth corresponding to that discharge, it would be found that the form required was curvilinear and consequently somewhat unsuitable for masonry construction. The theoretically true form can, however, be very approximately represented by a trapezium, and it is the

form of this trapezium which is required in practical applications of the problem

To determine this trapezium in any given case we require to find two unknown quantities, the base width and the inclination of the sides, and these two quantities are obtained in the following way The general equation for the discharge through a trapezoidal notch contains both these quantities—this equation is used twice over, being written down for two distinct values of the depth and the corresponding discharges, thus giving two independent equations for the two unknown quantities The notch so calculated gives of course only approximately true results for other values of the depth than the two particular values chosen, and thus in practice it causes for these other values a certain amount of raising up or lowering down of the water level In these cases, however, with two properly chosen depths for calculation, the amount of this deviation from strict accuracy can be made inappreciably small within the working range of discharges

In the case of the actual problem arising in practice, the following points should be noticed —

(a) The actual discharge to be passed over any fall is the amount required down stream of it

(b) *Any particular value of this discharge may have to be passed* with different values of the depth in the up-stream reach, since it may be required when all the up stream off takes are open, or when they are all closed, or in any intermediate case

(c) Thus in the practical problem though it is possible to at once choose the values of the discharges to be used for calculation, yet the depths in the up stream reach corresponding to these discharges are within certain limits indeterminate.

(d) At the same time the depths in the lower reach in the neighbourhood of the fall are quite determinate, and supposing y_m and y_o to be the depths corresponding to the greatest and least discharges ever required here then the two values to be employed in the formula for calculation are those values of the depth in the up stream reach which correspond to the depths y' and y'' in the lower reach,

y' being equal to $y_o + \frac{1}{4}(y_m - y_o)$

and y'' being equal to $y_o + \frac{3}{4}(y_m - y_o)$

(e) The depths in the upper reach corresponding to y' and y'' in the lower are strictly speaking indeterminate for the reason

given in (*b*), and it is only possible to ascertain certain limits within which each must lie. Since, however, some definite value of the depth in the upper reach is required for substitution in the formula of discharge through the notch whose dimensions are to be calculated, it is necessary to choose arbitrarily some such value lying between the limits of the actual value.

(*f*) Take y_m the full supply depth in the lower reach and find the limits of the corresponding depth in the upper reach, then carefully consider the circumstances attending the discharge in the upper reach (e.g., the number of off-takes in the reach, the average volume likely to be drawn off by them, and its ratio to the total volume discharge through the reach), and choose the value d_m which seems the most probable value of the upper reach depth in times of full supply to the lower reach. Then calculate $d' = \frac{d_m y'}{y_m}$ and $d'' = \frac{d_m y''}{y_m}$ and use these values of the depth for substitution in the formula of discharge through the notch.

(*g*) The usual formula for discharge through a trapezoidal notch with clear overfall and no velocity of approach, is

$$Q = 5{\cdot}35\, c\, (l + {\cdot}4\, nd)\, d^{\frac{3}{2}}$$

where l is the base width and n the side slope.

Substituting in this the values d' and d'' with their corresponding discharges Q' and Q'', we have two equations for the determination of l and n.

The quantities l and n, as found above, fix the profile of the notch, but from an engineering point of view there still remain several details to be considered before the design is complete, e.g., the thickness of the notch walls, the height to which they should be carried, etc. This is best illustrated by the diagram of a notched fall in *Plate* VI, which shows one of the latest forms of notch in use on large distributaries.

Fig. 1 gives the plan of the fall, AB is the horizontal trace of the vertical plane in which the calculated profile of the notch lies, CD that of the upstream face of the notch wall, and EF that of the down-stream face. The thickness from CD to AB is rather more than double that from EF to AB, and this latter varies from about 6 inches in small notches to 18 inches in large ones. The circular arcs IJ and GJ′ on the

down-stream side are arcs of 45°, those on the up stream side are of about the same amount, but of only one quarter the radius, the remaining portion KL of the up-stream face being a plane inclined to the vertical and also sloping back from CD KL is the horizontal trace of this plane and makes an angle of about 45° with CD being a tangent to the small circular arc KJ.

GHI is called the lip of the fall, it is semi circular, and is supported from beneath in the manner shown in the elevation which represents half the notch from the up stream side and half from the down stream side

The height h of the notch should be that of the estimated full supply depth a depth which may of course occasionally be exceeded by the actual water depth The height h of the side walls should be such as will ensure them against being topped when the estimated full supply depth is unavoidably exceeded.

It might be noted that a notch is technically described as "*too loose*" when it causes the water level to drop on approaching the notch, and as "*too tight*" when the water level rises. A loose notch has the effect of increasing the velocity of approach of the water, and so causing a scouring action along the bed of the channel immediately above the fall A tight notch on the other hand diminishes the velocity of approach, and this tends to produce silting on the channel bed In distributaries or small canals, when the range of variation of supply is not great, neither of these actions will be sufficiently strong to do any damage, but in channels carrying large supplies (300 cusecs or over), and where the range of variation is correspondingly great, either action may cause considerable damage, unless provision be made to prevent it On this account it seems doubtful whether notched falls give really satisfactory results in the case of large supplies, and in this case it is almost always necessary to make provision for the raising or lowering of the notch cill, by placing sleepers horizontally across the bottom of the notch in two grooves prepared for them in the side walls These sleepers may then be pulled up when it is necessary to lower the notch cill, i e. when the notch becomes too tight, while others may be placed on top of them when it is too loose

This, of course, necessitates a continual watch being kept on the water level, which is a disadvantage, and consequently a simple notched fall is always preferable when possible

For practical examples of the design of these falls and for the case of notches with incomplete falls the student should refer to the pamphlet quoted above.*.

12. Bed slopes for Main Canals.—The following table shows the mean velocities in the upper reaches of some Indian Canals in the United Provinces and the Punjab :—

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* NOTE.—I do not accept the definite general statement that the correct form for falls is that known as a notched fall. If we presume that (i) supplies in all channels must of necessity vary largely in volume and (ii) it is essential to have normal surface slopes for all volumes, then and then only, will the notched fall be the best theoretical type. The question is discussed under the design of falls in the chapter on works. G. T. A.

Canal		Dimensions of channel		Results, feet per second		Remarks.
Name	Site of observation	Mean width	Depth.	Mean velocity	Discharge	
		Feet	Feet.	Feet.	C Feet.	
Ganges	1¼ miles below Head.	159	10	4 80	6 969	Soil shingle, no scour
	44 ,, ,, ,,	177	8 6	3 21	5 024	Soil loam, bed scoured, velocity too high.
	93 ,, ,, ,,	138	6 4	3 36	3 147	Soil stiff loam, bed unchanged.
	193 ,, ,, ,,	80	4 4	3 99	1,400	Soil clay mixed with kankar, bed slightly scoured
Lower Ganges .	2 ,, ,, ,,	234	8 28	2 331	3 642	Soil sandy, bed silted velocity too low
	Head of Bhognipur Branch	63	6 7	2 85	1,089	Soil loam bed unchanged, velocity correct
Sirhind ..	Ghari	194 8	8 665	3 16	5,173	Soil sandy clay bed slightly silted
	Head of Abchar Branch	93 8	5 258	3 09	1 531	Soil sandy clay, bed slightly scoured This site has passed higher velocities
	43rd mile	73 6	6 333	3 5	1,503	Soil sandy clay bed, slightly silted
Agra	1½ ,, below Head,	90	8 5	2 30	1 533	Soil sandy loam no scour, no weeds
	11 ,, ,, ,,	70	7 2	2 56	1 294	
Bari Doab .	Lower end, Main Branch upper,	116	6 825	2 95	2 340	Soil loam This velocity is just about as much as the soil will stand—might be less with advantage
	Head of Main Branch, lower	75	5 065	3 48	1 322	Soil loam This velocity is more than the soil can stand and there is a good deal of erosion
	Head of Lahore Branch,	53 4	5 315	2 54	720	Soil loam Soil might stand a little more velocity—no erosion
Swat River	Near Head, ..	36	5 27	3 2	611	Soil very stiff clay Maximum velocity =3 5 feet which does not cut the soil
Sardah (proposed) ..	Head of Main Canal,	278 5	8 5	2 96	7 006	Soil sandy velocity reducible by means of regulators
	,, Gogra Gumti Doab	138	8 5	2 742	3 027	Soil loam The Sardah Canal is only as yet projected—the velocities are calculated
	,, Fyzabad Branch,	110	10	2 51	2 639	
	,, Benares ,,	150	10	2 687	4,030	

The original slope designed for the Ganges Canal in its upper reaches below the torrent works was 1·5 feet per mile; this was reduced in the modified design to 1·25, which caused extensive erosion of bed and damage to works—the present water surface slope may be taken as 0·75 in the upper reaches.

13. **Varying results of clay and sand deposits.**—The slope given to the Lower Gangss Canal main line was 0·5833 foot per mile: this was the maximum inclination economically available, and it was not found sufficient to effectually prevent the deposition of silt or the growth of weeds. With the section as designed on the Agra Canal the low slope, 0·45 foot per mile, has neither caused serious deposition of silt, nor the growth of weeds. This seeming contradiction* to the results of the slope of the Lower Ganges Canal may be explained,† partly by the fact that large borrow pits, to provide earth for the embankments of the latter canal, were dug in the bed, which appear to have acted as efficient nurseries for weeds, and partly by the great differences in the quality of the silt carried by the Jumna (which feeds the Agra Canal) and the Ganges rivers. The silt of the Jumna is largely composed of a finely divided clay, which, though very fertile when once thrown down, is yet only slowly deposited, except in practically still water. The Ganges silt on the contrary is mainly coarse sand which is quickly deposited even in running water. This quick deposition of silt also tends to increase the growth of weeds which, as before noted, do not thrive in discoloured water: thus, on the Agra Canal, the main line is free from weeds, which grow freely in still water and distributary channels where the supply is clear; and the great luxuriance of the weeds in the Agra distributaries, compared with the Lower Ganges distributaries, is undoubtedly due to the superior fertility of the Jumna water. From the above it will be seen that the character of the river water should largely influence the decision of the proper inclination to be given to the bed of the canal and distributaries.

14. **Velocity not constant with fixed slope.**—Whatever slope is ultimately fixed, the resulting velocity will not remain constant in an

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* The ordinary depth of supply in the Agra Canal is 2 to 3 higher than that of the Lower Ganges.

† The weeds have disappeared to a great extent from the Lower Ganges Canal since the bed was narrowed, thus increasing the depth.

open channel, for the depth and quantity of supply are always liable to change in accordance with the sudden variations in supply and demand to which Indian canals are so liable nor will the effects of the same velocity be constant at all seasons of the year, for the supply, heavily laden with silt, which enters the canal during the times when the feeding river is in flood has not the same scouring power on the bed of the channel as the clear water passed in during the cold weather That this is the case is abundantly evident from a consideration of the changes which the beds of the great rivers undergo after the floods, when the clear supply with a low velocity invariably deepens the cold weather channel and removes silt deposited during the floods This action should not be confused with the extraordinary holes so often formed during great floods which are always due to whirlpools or local scour caused by obtructions, and not to the mean velocity of the flood current Again on the Ganges Canal the holes in the bed caused by erosion before the velocity was reduced, are more or less filled up with silt by the supply passed down during the rains while in the cold weather the clear supply which enters the head by gradually picking up this sand again becomes silt laden long before it reaches the tail of the canal

15 **Regulators advantageous** —The evils consequent on the above mentioned changes in the condition of the supply, will be felt most in the main canal, above the point where it separates into branches in which latter it is possible to counteract them by judicious regulation and this length may with advantage be provided with regulators spaced apart at distances sufficient to allow of the surface slope being altered by the introduction or removal of planks to suit the changes in quantity and quality of the supply. All masonry falls necessitated by excess inclination of the natural ground level, can also be utilized as regulators by having properly adapted raised crests * Thus it will be possible to give the canal bed a slope sufficient to cause the maximum safe velocity with the average supply running and by the provision of these intermediate regulating arrangements to reduce the velocity for the maximum supply This procedure is also economical as a rapid velocity requires a smaller area of channel for a given supply, and if too small a slope is given in the first instance, the remedies to it will be most expensive.

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* Notched falls not nearly so suitable G T A.

It is not necessary to incur heavy expenditure on such regulators;* narrow piers resting on a floor, pitched above and below, with a boat bay on one side, will be found amply sufficient, and even on navigable lines the necessity of locks will be but rarely felt if the fall over each work is kept at one foot or under.

16. **High slopes sometimes permissible.**—When the upper reaches of the canal pass through boulder or shingle soils much higher slopes and velocities can be given with advantage. Thus the Ganges Canal supply channel, in the boulders above the canal head, proper, was excavated on a slope of 24 feet to the mile, and parts of the Eastern Jumna Canal near the hills have even higher slopes. The Ganges, Eastern and Western Jumna Canals take out from the boulder beds of these rivers where they debouch from the Siwalik hills, and in this respect differ widely from the Lower Ganges and Agra Canals, which are fed by means of weirs founded in the sandy beds of the same rivers.

17. **Importance of Soil Sections.**—Before finally leaving the question of inclination of bed, it is necessary to draw attention to the great importance of soil sections. When the upper part of the Ganges Canal was being dug, it was found that the superposed clay soil, supposed to be of considerable depth, was only 3 to 10 feet thick, and that it overlaid pure sand, which would have formed the bed of the canal channel. If the original section had been proceeded with, this discovery would have necessitated expensive alterations in the works.

Soil sections at frequent intervals should therefore be made along the line of main canal, to beyond the estimated depth of bed, from which a geological section, showing also the height of subsoil water, can be prepared, and plotted on a suitable scale; this necessary information can be readily acquired by sinking pits or boring. When time and funds are

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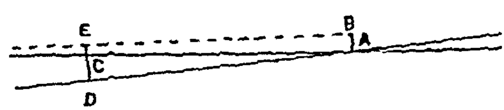
* Regulators spaced 5 to 8 miles apart will be effectual for ordinary slopes. The effect of the obstruction is given by Dupui's formula, viz, ordinary log y=ordinary log $Y - \frac{r}{0{\cdot}77 \times P4}$

New surface
Original surface
Horizontal line
AB the rise at any point $A=Y$.



CE „ „ „ „ $E=y$. The distance from A to $D=S$.

CD the surface slope in distance $S=r$

P=mean depth in distance S.

Example.—Canal with surface slope of 0·74 per mile and depth=8 feet. Sleepers causing a rise of one foot are put in at A. To find rise in water surface level 5 miles above—

$$\text{Log } y = \log 1{\cdot}0 - \frac{0{\cdot}74 \times 5}{0{\cdot}77 \times 8} = 0{\cdot}00000 - 0{\cdot}60065 = 1{\cdot}39935,$$

therefore $y=0{\cdot}2508$, and surface slope has been reduced from 0·74 per mile to 0·5902.

available, similar information should be collected for the larger branches, the cost will be well repaid

18 Calculation of Discharges —No reference has been made regarding the formula for calculation of discharges in channels The Tables* by Jackson, founded on Kutter's formula, and other well known publications † meet all requirements in this respect

19 Position of bed line on Canals —As regards the relative positions of the water and ground surface, it is best to keep the main canal well in digging with the water surface not above ground level This of course, owing to breaks in the watershed, and the inevitable irregularities of the ground surface, is not always, possible without entailing an injurious loss of head but every effort should be made to avoid embankments which are expensive, liable to cause percolation, and necessitate extensive borrow pits often the cause of swamps.

20 Distinction between a Canal and a Distributary.—In general the distinction between a canal and a distributary is at present founded on the discharge thus every channel discharging at its head 200 cusecs or more is considered a canal, when not more than 200 or less than 10 cusecs it is classified as a major distributary, and when the discharge is less than 10 cusecs the channel is classed as a minor. The term minor is, however, only applied to such channels as are taken off from majors as distributaries, and is not applicable to the tail portion of a major, even though its volume may fall below the prescribed limit of 10 cusecs It is, however, probable that in the future as soon as improvements now in progress are completed, channels from which there is no irrigation direct to the fields, will be classed as canals, and all others as major and minor distributaries, and this simple distinction is here adopted

21 Position of bed line on distributaries —Attention has here been called to the distinction between canals and distributaries, as the main difference in their engineering treatment consists in the locating of the bed line, which on distributaries ought to the fixed so that the water surface may be kept at, or just above the general level of the ground surface. This is generally possible owing to the manner in which such small channels can be kept closely to the watershed line, and to their small discharges inexpensive works allowing of a greater latitude in the selection of appropriate slopes Some authorities consider it advisable to

* Canal and Culvert Tables by L D A Jackson, A M I C E —W. H Allen & Co., London

† Discharge Chart by Captain Clibborn, I S.C —College Book Depot, Roorkee
Also Kennedy's diagrams and Garretts' diagrams

keep the water surface a little below the ground surface, in order that the village water-courses may be in digging near the distributary. This practice is suitable where the soil is bad and where the watershed side slopes are steep, as it prevents waste, and the supply quickly rises high enough for flow irrigation, but it is unnecessary with good soil and properly designed water-course channels.

22. **Embankments on distributaries.**– It is not always possible to avoid embankments even on distributaries, and occasionally a high level line may be preferable to a long *detour*, a passage through high sand, or a debarred tract. Before deciding such cases, the chances of obtaining sufficient supplies of good puddle clay within a reasonable distance ought to be enquired into, and the nature of the soils traversed should receive careful considerations, as there are extraordinary differences in the powers of absorption of different soils. The best idea of their capacities in this respect will be obtained by noting the effects of the rainfall. A relatively high sub-soil contour early in the rains may indeed be accepted as an infallible sign of a porous soil: it may, however, be noted that water-tight channels can be constructed in pure sand by using puddle linings, and protecting the banks and slopes with thin coverings of good soil.

It does not by any means follow that in all cases percolation is greater from embankments than cutting, when as often is the case, the upper surface soil is loam and the lower sandy, the cutting will naturally percolate most. In well made banks the soil being thoroughly broken up and consolidated does not present the natural strata and fissures of the cutting which undoubtedly tend to leap the water to the subsoil.

23. **Dimensions of channels.**—The depths of canals usually vary between 12 and 5 feet and of distributaries between 6 feet and 1 foot, the cross section being a flat trapezoid with side slopes 1 to 1 for ordinary soils. There is no fixed proportion of bed width to depth, but very wide shallow sections are to be avoided,* as liable to weed growth, difficult to maintain and expensive to make. On main canals the proportion will depend on the nature of the sub-soil, the works, and the demands for navigation (*if included in the design*).

* On this question Punjab *Irrigation* Branch Paper, No. 7, may be read with advantage, but it must be remembered that weed growth in a distributary is often more objectionable than silting up.

24. Distributary cross sections.—For distributaries the proportions here given, though not by any means a fixed rule, will be found suitable for ordinary soils

D=Depth.

Bed width=D×2.

Height of banks above water surface=$\frac{D}{2}$, but never less than 1 foot.

Top width of banks=bed width, but never less than 3 feet.

As a rule, for distributaries running with a general direction North and South, the East bank should be selected for the bridle path to avoid the reflection from the sun shining on the water.

Inner side slopes usually 1 to 1.

Outer " " " 1½ to 1, but this depends on soil.

Unexcavated berm outside banks=D.

As above noted, the channel is usually constructed with internal slopes of 1 to 1, but these in time, by the action of the running water, are hollowed at the base and accumulate silt at the water surface, the ultimate slopes closely approximating ½ to 1 (*see* thick lines on sketch. *Fig.* 41, *Plate IV*). After a distibutary has been running some time the wetted perimeter becomes covered with a more or less water-tight lining of fine clay, which it is important to preserve as far as possible; and as the ½ to 1 section appears the natural one, it is well to accept it as final, and to design the masonry profile* on ½ to 1 slope, taking care to increase the bed width so as not to reduce the water section It need hardly be mentioned that the banks would not stand at the ½ to 1 slope when first constructed before the soil was consolidated by the action of water and the silt lining.

Some designers have considered this silt lining and the naturally deposited berm efficacious enough to warrant the banks being thrown back several feet so as to allow for the deposits of a berm 2 or 3 feet wide. Experience has, however, shown that, except with distributaries carrying large quantity of silt in suspension, the deposit is too slow to counterbalance the evils of a channel being left abnormally wide, shallow, and subject to weed growth for several years.

Note on paragraph 24.—The student is recommended to read 'Design of canal and Branches' paragraph 5 of 'Irrigation works' by Bellasis.—1913, which is up to date in the scientific designing of channels.

* These profiles are usually built at furlong distances as a permanent guide to the bed levels and cross sections It is, however, a much better practice to build them at 1 000 feet intervals, and to work out slopes, etc., per 1,000 feet instead of per mile, making the ground surface distance measurement marks of the distribuary quite independent of the bed marks.

The *maximum* ratio of bed width to depth of water is given on page 50 and is as follows:

Discharge in cusecs ..	10	25	100	200	500	1,000
Ratio	3·5	4	4·5	5	6	6

The ratio of 2 to 1 given in paragraph 24 may be accepted as a *minimum* and only for volumes under 20 cusecs.

The *two important points to consider in fixing* mean velocities for the channel are:

(*i*) The maximum velocity the soil will stand without erosion.

(*ii*) The minimum velocity needed to prevent undue deposits of silt in the upper reaches.

As regards No. (i) the following table may be accepted as approximately correct:

Light loam	1·5 to 2·0 ft per sec.
Good loam	2·0 „ 2·5 „ „ „
Gravel or clay	3·5 „ „ „
Stiff clay or pebbles.. ..	4·0 „ „ „
Broken stone and pitching ..	5·0 „ „ „
Plain concrete	6·0 to 7·0 „ „ „
Brickwork and cement concrete	8 ft. per sec.
Sound rock	10 „ „ „

No. (ii) the minimum velocities needed cannot be so easily disposed of. Water in motion in open channels does not move in horizontal layers—there is a regular interchange between the top and bottom layers, and the silt-carrying capacity depends on the vertical component of the forward velocity. If a particle of silt is to remain in suspension indefinitely, the reaction of the bed of the channel must be of sufficient strength to force it up to the top, after each time it reaches the bed. Obviously for every given depth of water and every grain of silt of specific size and weight, there is a corresponding minimum forward velocity needed to give the requisite minimum reaction off the bed, which will carry the silt up to, or near the surface, along with the water which is moving up from the bottom to the top.

Mr. R. G. Kennedy experimented with the silt carried in the Punjab canals and gives the following as the minimum mean velocities, designated critical velocities, and denoted by Vo, as required for various depths to keep channels free of silt deposits.

Depth.	Vo.	Depth.	Vo.	Depth.	Vo.
1	·84	4	2·04	7	2·92
2	1·30	5	2·35	8	3·18
3	1·70	6	2·64	9	3·43
				10	3·67

It follows from the foregoing remarks, that we may design two channels each carrying the same volume at the same mean velocity, but only one of the two capable of carrying silt in suspension.

Example	No. 1	No 2.
Bed width	3 2	13 5
Depth of water	5 0	2 0
Inner slopes	½ to 1	½ to 1
Water surface slope .	2 in 1 000	·35 in 1 000
Mean velocity . ..	1·4	1 4
Discharge	40 cusecs	40 cusecs
Vo or critical velocity ..	2 35	1 3

N B.—Velocities are due to water surface slope and not to bed slope

Both channels will have a mean velocity of 1·4′ per sec This velocity will be ample to carry silt when the depth is only 2′, as Vo for this depth is 1·3′ per sec but will be hopelessly inadequate to carry silt when the depth is 5′, for which depth a mean velocity of 2·35′ per sec is needed

The mean velocity is only one factor in deciding whether silt will or will not be carried in suspension, a second and equally important factor, is the depth of water.

25. Economical depth of digging.—The most economical depth of digging for a distributary channel is that by which the earth from the channel will just suffice to make up the banks of the distributary Outside borrow pits, though unavoidable at times, are always objectionable as they sometimes render land unculturable during the whole of the year, and nearly always spoil it for the wet season's crop Moreover, from their proximity to the channel, they intensify the evils of percolation if it exists, the damage would be much greater than it actually is, were it not the custom on canals to limit the depth of excavation of borrow pits to 1 foot. Excess spoil from the channel is also objectionable as it involves avoidable expense and the occupation of extra land

If the cross sections recommended in paragraph 24 are used the most *economical depth of digging will be obtained by keeping the water surface* at, or very slightly above the ground level, and it will be well to consider this when laying down gradients

26 Distributary cart ways—Cart ways are not usually provided for distributaries, but on major lines, particularly when the country is not well provided with roads, they are very necessary adjuncts to ensure efficient inspection. Cart ways when necessary can be economically provided, by taking up a strip of extra land 20 feet wide outside the toe of the riding bank, and either simply levelling the ground surface, or raising it slightly with earth from a boundary ditch on the outside edge

The principal expense consists in providing crossings for the field water-course outlets, as the supply from these has to be carried in pipes under the road. Where the roadway crosses bridge ramps, it is best to gradually raise it to the height of the distributary banks, making the combined width 20 feet; this ensures solid and substantial earthwork at points particularly liable to wear and tear from public traffic.

27. **Canal berms and cross-sections.**—The main canal is always provided with a roadway wide enough for wheel traffic, as the water surface is generally below the ground level. Spoil is as a rule in excess, and the ordinary practice is to throw the spoil back to allow of a berm 5 to 10 feet wide between the channel and the roadway. This is very necessary on large canals, which partake more or less of the nature of rivers and are liable to under-cutting of the banks from side currents and eddies. If the berm margin was not allowed, the general alignment of the canal might be lost from the roadway being cut away in places. This berm being natural ground has an irregular surface; the appearance of the channel is much improved when the berm is dressed to a regular height above the water level—this, for average digging, should be 2 feet above maximum supply. In the upper reaches of great canals where the digging is generally excessive, the berm may be kept at a higher* level.

28. **Canal roadway.**—A typical cross-section of a main canal 100 foot bed and 8 feet depth of water is shown in *Fig.* 42, *Plate* IV. AA are boundary fences, and the width of land occupied is 500 feet. It is usual to afford space for plantations of trees fit for timber, fuel, and occasionally fruit. The enlarged section of riding bank shows the ordinary dimensions given, in detail: the roadway is embanked 3 feet above the berm B, which is on the natural ground level. A side slope of 1 in 40 is given to the roadway to keep it clear from rain water, which is carried by the side drain D into cross drains dug through the spoil at intervals of about one furlong apart; the side drain is sloped gently from the centre of each furlong to the cross drains on either side. (*See Fig.* 43. *Plate* IV.).

29. **Canal tow-path.**—The roadway is provided with a tow-path C, both for the use of men towing boats, and as a protection to the roadway on the canal side: this should be substantially made of stiff soil, or it will be worn away by the rains in a few years.

30. **Drainage of spoil.**—The spoil is shown with a slight cross slope away from the canal, and a ridge on the edge. A small masonry-lined

*Where the country level is below the full supply level, it is best to leave the berm at country level. Silt will deposit on this berm and in a very short time there will be a berm at full supply level which will have green grass all the year round.

shoot is required between each pair of cross drains to carry off the rainfall and prevent ravining. It is a good plan to divide the surface of new spoil into compartments with small ridges, and to allow the rainfall to soak in until the earth is consolidated A little attention to small details like the above is well repaid in after years by the neat and workmanlike appearance the earthwork presents, when once covered with good grass it needs no attention beyond keeping the drains cleared

31 **Disposition of spoil banks**—The usual practice is to throw up the spoil with a fixed width and heights varying with the amount of excavated earth The result is not always pleasing, owing to the irregular outline of the upper surface of the spoil it is much better to make the width variable and the height an even distance above the water surface For considerable lengths within which the depths of digging do not greatly vary the change of width is not very perceptible from the road way, and the regularity of the spoil line gives a finish to the work, and simplifies the arrangements for drainage

32 **Canal fencing**—The ordinary fence along the boundaries of the canal land is a trench and bank (*see Fig* 44 *Plate* IV)—the latter planted with a live fence of aloe plants (*agave vivipara*) or other hedge plant The earthwork is, however difficult to maintain, and the villagers frequently break down the fence to make paths for their cattle to graze on the grass and young trees of the plantations Many forms of barrier have been tried but none with marked success, except substantial wire fencing this however, is expensive, and the expenditure is doubled when both sides of the canal have to be enclosed Trees, moreover, do not thrive so well in narrow as broad strips and it would be an improvement on the present cross section to take up a double width of land on the riding bank side, planting that only, just enough land being taken up on the other side to allow of a substantial bank being made, or for spoil where it is too much in excess, to allow of its being economically placed on the riding bank This procedure would halve the cost of fencing and the labour of inspection of the plantations. To make the fence thoroughly efficient it should be connected with the parapets of the canal bridges, inspection gates being provided for the canal road crossings All public traffic can then be confined to a fair weather roadway running outside the fence, this road will also facilitate the inspection and repairs of the fence.

33 **Height of banks above bed on main canals**—The height to which banks should be made above the maximum water surface on main canals must depend a good deal on the most economical disposition of the spoil which, as a rule is in excess The cost of the land occupied,

when it is valuable, has to be considered, bearing in mind that high spoil banks are difficult to maintain, plant, and keep free from jungle. As a general rule, the cost of lifting earth each additional foot is equal to the cost of carrying it an extra lead of 10 feet. One objection to a very high spoil bank is, that it cuts off the view of the surrounding country, for the roadway cannot be raised much without entailing great expense in repairs of holes during the rains; the denuded earth from high spoil also chokes the side and cross drains, and on the whole, except in special situations, it will be found most economical in the long run to keep the spoil level from 5 to 7 feet above the ground. In embankments the top of banks should not be less than 5 feet above water surface, with top widths of 25 feet and outside slopes of 2 to 1 or 3 to 1. Main canals, from their great length and large works, are much more exposed to floods than distributaries, and no possible precautions against breaches should be neglected.

34. **High canal embankments.**—As main canals have often to be carried across large drainage lines in order to gain the *doab*, for the irrigation of which they are designed, the passage of deep river valleys by high embankments leading to and from aqueducts has to be considered. The two most notable examples of this class of work are the Solani embankment of the Ganges Canal, 2 miles 4 furlongs and 606 feet long, with the bed raised from 15 to 18 feet above the ground surface, and the Kali Nadi embankment, a somewhat smaller work of the same class on the Lower Ganges Canal. Both these huge embankments have stood the test of time and high supplies in the canals most successfully and with marvellously slight subsidence. Considering their height, this stability is undoubtedly due to the careful and workmanlike manner in which they were constructed. The Kali Nadi Aqueduct was destroyed by an unprecedented flood in 1885, following a rainfall of over 81 inches in 24 hours, but the embankment stood absolutely uninjured.

The construction details of embankments belong properly to the Manual on "Earthwork." It is, however, necessary to show the position and dimensions of the earthwork and the puddle walls on the longitudinal section. If the clay for the puddle is of good quality and well mixed, a 2-foot top width, with the sides battering at a slope of 1 in 10, will be found sufficient to entirely stop percolation through the banks (*see Fig.* 45, *Plate* IV).

The puddle wall is best placed well inside the earthwork, where it will be protected from the effects of the atmosphere, and for the same reason it should not be carried up to the roadway level, but kept one to two

feet only above full water surface to provide for floods or extraordinary supplies. The foundation ought to be well bedded in the natural soil Puddle linings for the bed are rarely provided as in most cases the expense would be great and a really well embanked bed is practically more impervious than a section of the natural soil at the same time it must be admitted that situations are met with where the provision of a water tight lining to the whole channel would in the end be the most economical and judicious practice A thoroughly water-tight channel not only saves the adjoining lands from injury by percolation, and the Engineer from obloquy but economizes canal water for use when it is really wanted If such a lining is deemed indispensable it is a matter for careful consideration, whether puddle or a thin Concrete lining should be employed—the saving in earthwork repairs and the possible reduction in the dimensions of the channel are in favour of the latter material.

By experiments made in 1889 90, Mr Dupuis obtained the following results —

Probable loss of water per mile in a canal channel 18 *feet wide at surface and* 5 *feet deep embanked in pure sand.*

If unpuddled .	2·65 cusecs
If puddled with one foot brick earth,	0·45 ,,
,, ,, ,, ,, black puddle	0 30 ,,

He also found that there was no advantage practically in 1 foot 6 inches thickness over 1 foot but that the advantage of 1 foot over 6 inches was considerable, also that good yellow clay was equal to black puddle

Probably the best possible lining for a large canal would be 1 foot of puddle with a few inches of concrete over to protect it from injury

35 **Discharges** —In order to determine the required discharge of the main canal at the head, as mentioned previously, it is necessary to work up from the very beginning, calculating out the demand for each water course and distributary and making all needful allowances for loss of water by percolation and evaporation The calculation of demand and needful supply for each water-course is quite simple when the irrigation from it is confined to a single village as it will be when the canal is the colonizing agency in previously uncultivated tracts, but to maintain this condition is very difficult it may be said impossible in practice when canal irrigation is introduced into settled and cultivated districts, because it is essential that the boundaries of the minor *doab* not of the village lands should be the limits of irrigation from any particular water course and when several villages or parts of villages have to be supplied from one water course, although the calculations of area and supply are simple

enough, the distribution must be complicated by proper rules ensuring that all parties are justly treated with regard to the times and quantities of water supplied to them.

It must be admitted that many distribution and administration difficulties will be removed if one uniform size of outlet pipe can be used, and the necessary variation in quantity of discharge secured by altering the head of water or increasing the number of pipes in particular outlets. As two cusecs is about the maximum supply it is judicious to allow to any private water-course, if the 6-inch diameter pipe, now the most popular size, be selected as the unit, it will be rarely found necessary to fix more than two* 6-inch pipes parallel to each other to give any required discharge; indeed, the average discharge of the private water-courses of a large system of canals under ordinary conditions will be found not to exceed half a cusec.†

36. **Duty.**—Having fixed on a standard size of outlet pipe, it is necessary to determine the *duty*, to be accepted per cusec for the canal or tract under consideration. This *duty* is the area which it is assumed can be irrigated by one cusec from a distributary *continuously* during the year, and it is necessary to be careful when dealing with the calculations for distributaries, minors and water-courses to remember to reduce this duty according to the proportionate times they are to be open for irrigation, or closed to allow of water being given to other branches. Thus the duty per cusec for a distributary open and closed each alternate week in the year will be half that for one continuously open.

The actual duty for any given tract must be determined by experience, the nature of the soil, the climate, the system of cultivation, and the arrangements for distribution. The figure assumed should, in any case, be one which it will require care and attention on the part of the Irrigation establishment to work up to, and yet not be beyond attainment under favourable conditions. It is true the duty is but an assumed figure for the purposes of calculation, but it has great importance, because if it is fixed too high, it will really reduce the percentage of irrigation allotted to the tract.

In Northern India a duty of 300 acres per cusec is now generally accepted as a fair figure to work by. This area, however, will be found

* Two 6-inch pipes with a head of 1·050 feet will discharge 2 cusecs.

† In actual practice it is found extremely difficult to put in outlets with varying heads of water to give the required varying discharges needed. In the United Provinces pipes varying from 3″ to 6″ diamater are used, the distributary is divided into reaches and in each reach the outlets are built all the same height above bed level; in the tail reach at bed level.

too low when the country has advanced to the stage of giving irrigation channels, more specially the smaller ones, an impermeable lining A [illegible] depth of 2·41 feet all-over the area, [illegible] if we compare this figure with the quantity of water used in irrigation from wells

Average depth of water in feet used for irrigation of different crops in the North Western Provinces and Oudh *

Tobacco	Potatoes	Sugar	Opium	Carrots	Gardens	Wheat	Barley
1 936	1 186	1 125	1 061	1 061	1 023	0 6778	0 465

Although for general purposes a duty of 300 acres per cusec is recommended, the fact that different climates, soils and crops require varying quantities of water for efficient irrigation, must not be lost sight of, nor neglected In comparatively damp climates sugarcane and wheat can often be matured with one or two waterings, while in drier climates they will require several. No comparison is possible between the quantity of water taken by rice and gram. A light soil will often absorb three times the quantity of water required for irrigating the same area in clay It is certainly possible with diligent inquiry to arrange discharges so as to fit in more closely with actual requirements than any average duty can, and where broad distinctions between climates, soil and crops exist, a varying duty should certainly be used, at the same time it must be remembered that too many refinements often lead to troubles, which are very difficult to cope with, and that there are other disturbing influences which may at times modify the results of the best arranged systems, such as variations in rainfall, caste of cultivators, and those changes in the classes of crops grown which invariably follow the introduction of canal water. In India the influence which race and caste has on cultivation is most marked, and the hired labourers, which enriched canal farmers often employ, are not nearly such economical workers as self-cultivating tenants

37 **Allowances for evaporation and percolation** —It is necessary to consider the question of allowances for both evaporation and percolation on canals, although it will be seen that there are some difficulties in the way of applying these allowances in practice Before dealing with the *amount* of loss due to these natural results of carrying water in open earthen channels, it will be advantageous to consider how they are likely to effect the discharge in different cases Taking first rivers and streams

* *See* Report on Construction of Wells for Irrigation N W P., published at Roorkee, 1923.

flowing in natural channels. These will lose water by evaporation and gain by percolation, and the loss from the first cause will be greatest when, as is usually the case in the Indian plains, the river flows in a broad shallow sandy bed exposed to great heat; yet it appears from the increase in volume of discharge which usually occurs, that the gain from seepage from the high lands to the river is generally greater than the loss from evaporation; and it may, therefore, prove economical in certain cases to carry water in the natural river bed in preference to a high level artificial channels.

The loss from percolation in large artificial canals passing through sandy or porous soil is very great until the soil between the surface of the ground and the subsoil water level has been saturated to its full limit (*vide* Article on Wells). (*See Fig.* 46, *Plate* IV.)

When this limit has been reached the loss will be reduced to the quantity of water which can pass off at the junctions of the frictional limits of saturation with the subsoil water line. This will be a small amount compared with the loss before saturation was reached, and any allowances made for percolation from canal in calculating effective discharge should be confined to this quantity, and not include the large early loss which will decrease year by year, and finally disappear about the time the full irrigation command of the canal is realized.

The evaporation loss from a main canal can be calculated with fair accuracy, and if it is considered necessary disallowance from the discharge for this and percolation can be made for certain fixed sections of the canal. The conditions on distributaries differ somewhat—the excavation for the channels does not cut so deep into the soil strata, the channels are more stable, and generally become lined with a fairly impermeable clay silt coating. Indeed, those properly designed to carry the exact discharges required, and kept carefully repaired to this section, in time become perfectly so lined: all this tends to reduce percolation, and, except in the case of large channels and very bad soil, it is probable that the supply rarely percolates far in the ground, at the same time there is a distinct loss from soakage when distributaries are wet and dry for short alternating periods.

Evaporation on distributaries is probably less than on main canals, owing to the banks protecting the surface of the water from being swept by the wind, and the shade of trees when these are allowed on the banks.

On very long distributaries an allowance for loss from these causes might be made with the advantage of more nearly equalizing the discharges from outlets throughout the distributary; but in most cases the

variation in soil and in the lengths of the water-courses themselves will have a so much greater influence on the actual value of any given discharge from an outlet, as to render such refinements in calculation both unnecessary and inexpedient.

In water courses the greatest loss is by seepage from the channels which are often daily opened and closed. The loss from improperly aligned and badly constructed water-courses is very great indeed, and as far as economy of water is concerned, there is more to be gained by attention to these often neglected channels than by any other measures the Engineer can take. It is from these channels the useful effect of the irrigation water is obtained, and from these also that the maximum waste occurs. No allowance of the nature made for the larger channels can be made usefully on water courses for loss, as the channels are the property of land owners and cultivators, and are unprovided with permanent regulating apparatus except at the head It may, however, be noted that in cases where disputes regarding the rights to certain supplies occur, the canal officer can be called upon to fix certain times for running supplies to particular localities, and in this case may with advantage give some extra period for irrigation to the tail portions of water courses to compensate for the distance the water has to travel.

38. **Evaporation.**—The amount of evaporation depends not so much on the temperature as on the rate at which the vapour can be removed from the surface of the water by the wind A high temperature has of course a considerable effect, and in America it has been noticed that there is more evaporatien from shallow than deep lakes, because the temperature rises higher in the shallow water Evaporation appears to proceed at night almost as much as during the day

Captain A. Cunningham, R E, made some experiments at Roorkee on the Ganges Canal to investigate the amount of evaporation with the following results—

Month	Rate in inches per diem.
February	0 14
March	0 12
May	0 15
June	0 12
October	0 13
December	0 10

Taking the mean of these results for 24 hours, i e 0·13 inch, the loss by evaporation on a canal, 50 feet wide in 50 miles of its length would be 1.65 cusecs, a small figure, if we consider the probable discharge of a canal of this dimension would be about 600 cusecs

Mr. Austin Ellis of the State Agricultural College, Colorado, after some elaborate experiments on evaporation in 1898, found the annual amount from lakes to be 41 inches, and 1 to 1½ inches per mensem from ice; 41 inches in a year is about equal to 0·11 per diem, which agrees very well with Captain Cunningham's results.

39. **Percolation**.—It is a most difficult matter to estimate with any approach to accuracy what the loss of supply due to percolation will amount to in a canal after it has been running for some years, the nature of the soil, the condition of channel, the depth of water, the temperature, and the position of the subsoil saturation level, all influence percolation.

It is evident that the loss will vary in different lengths of canal, be greatest in porous and less in compact soils and clay. In most main canals the first few miles of channel will have the bed level below the natural saturation level, where there will be more gain than loss, and as it is probable that every canal line will pass through tracts varying greatly in porosity, it will certainly be advantageous to identify the most porous sites and arrange for a remedy when this is possible.

In Colorado the State Agricultural College (1898) made some experiments on the seepage from canals which showed (as found in India) that the loss decreased when the soil became saturated; that it increased with the temporature,* being about twice as much as 80° as at 32°; that the loss was lessened by any process which forms or tends to form an impervious lining or coating of clay or silt; and that in the prevailing Colorado soil the loss may be put at from 1 to 2 feet per day over the whole surface of the canal.

This is a very large amount, but it is probable that the soil in Colorado is generally more porous than what is usually met with on Indian canals.

Mr. Dupuis in 1889-90 made some experiments in India to determine the value of clay or puddle linings for canal channels, and found that the probable loss of a canal channel 18 feet wide at surface and 5 feet deep, in loose sandy soil, would be 2·65 cusecs per mile. For a canal 50 feet wide in 50 miles, this represents about 368 cusecs, more than two-thirds the discharge of the canal, and it is probable that the whole supply of a canal in such soil would be lost in 70 or 80 miles.

When the Ganges Canal was first opened over 500 cusecs of the supply were lost in sand hills through which the channel passed about 30 miles from the head; this loss continued for many years, though on a

* The author experienced the same result when experimenting on the passage of water through sand in 1896.

reducing scale, until the soil was fully saturated, and the loss now is not remarkable in this length These last instances are more instructive as samples of the immense loss that occurs in certain localities, and of the necessity of counteracting it, than as guides to the normal loss which must occur in unlined channels of earth where all possible precautions have been taken On the older canals of the United Provinces and Punjab in India, the discharge carefully measured at different points, show the following average losses, viz, in the Punjab 8 cusecs for each million square feet of wetted surface, and on the Ganges a comparatively old canal in good order, 15·6 per cent of the discharge in 195 miles

The actual mean loss on the Ganges Canal in 197 miles was about 874 out of 5 500 cusecs and applying the other records to canals of somewhat similar dimensions, it appears that the losses may be expressed as follows —

Colorado Canals,	0·231 to 0 46	per cent of discharge per mile
Punjab*	.. 0·165	„ „ „ „
United Provinces Canals	0 082	„ „ „ „

It is evident that these losses include evaporation (vide para 40) which at 0·13 inch of surface exposed, will be 0 0025 per cent of discharge per mile The Colorado soil appears to be naturally porous the Punjab soil is somewhat sandy, and the canals are generally more recent than those in the N W Provinces and for general purposes a combined loss of 0·10 per cent per mile would appear sufficient for project calculations, that is to show what the loss will be when the canals have been running for a long series of years

Although allowances cannot usefully be made on village water courses for loss of water by percolation and evaporation it is interesting to inquire into the actual amount of this loss, for which reliable figures are available from the results given in the papers relating to the Construction of Wells for Irrigation, published at Roorkee in 1883 It must be borne in mind that these figures relate to well water-courses which are usually

* The most approved formula for loss by absorption in Punjab Canals is $P = C\sqrt{d}\,\frac{W.s}{1000000}$

where P=loss by absorption in any reach per second in cubic feet.
c=a constant usually taken at 3 5
d=depth of supply in feet
w=width of water surface of reach in feet
L=length of reach in feet

In all but very small channels W is practically identical with $(m+\frac{2s}{3})d$ and the absorption may therefore be taken as varying with $(m+\frac{2s}{3})d^{\frac{3}{2}}$

constructed much more carefully than the average canal water-course, yet the mean loss is shown as 2 cubic feet per foot run of water-course for a working day of nine hours.

Experiments made on the Ganges Canal about the same time showed that out of a total supply of one cusec there was a loss of 0·5 cusec in a distance of 1¼ miles, the soil being sandy for one mile; this for a day of nine hours=2 cubic foot per foot run also.

This loss of half the discharge in 1½ miles shows the enormous gain that would result from giving water-courses an impermeable lining.

40. Tatils.—*Tatils* are periodical closures of the whole or portions of channels for the purpose of regulating the distribution of the supply. There are many sound objections to continuous running of distributaries—it interferes with repairs, necessitates constant small supplies instead of alternating large ones, and it militates against economy of water to some extent, as cultivators are inclined to waste a supply which is always before their eyes in apparent abundance. On the other hand, there is a certain loss of water due to the channels being alternately dry and wet: this, however, will be largely compensated for if the channels are carefully examined and cleared to the calculated sections during the dry periods, and on the whole, an alternate weekly closure of distributary heads, combined with constant running of all their water-courres during the open period, is recommended. This system will of course involve doubling the discharge of the distributary for a given duty.

Section or internal tatils, in which the distributary itself is divided into a number of parts to be opened and closed for water-courses running alternately, are not recommended: this system was, and is even now in places, extensively practised on the older canals in India, and often was the only method by which water could be forced to the tails of badly designed channels. Its enforcement necessitated frequent appeals to law, and was a constant temptation to malpractices by the inferior canal officials, who in outlying districts could make a large income by merely shutting their eyes to thefts of water, or breaches of rules. There was also a great loss of water due to the heading up necessary in certain sections to force the supply lower down.

41. Six-inch pipe discharges.—The following Table on next page gives approximately the discharges under different heads from 6-inch circular *colaba** outlets—this size of outlet is probably the best suited for general purposes.

* Vernacular term for outlet pipes.

When fixing the position of outlets with reference to the water surface the ground levels should be considered it will often be better to give a double or even a treble pipe outlet discharging into a common channel with a small head in preference to a single pipe outlet with a large head

The *colabas* are supposed to have a clear outfall and no more, i e the water surface in the receiving channel is taken as level with the upper surface of the outlet When the water course is in embankment, arrangements should be made by means of masonry cills to preserve this condition When the water course is in digging, necessitating lift irrigation, precaution is not so necessary indeed, irrigators by lift may well be allowed every advantage, in order, as far as possible, to foster this most economical system of distribution Moreover, the area allowed for canal irrigation in each village being limited and under control, and lift irrigation requiring less water than flow, there will not be much temptation to increase the discharge.

* *Discharges from a 6 inch diameter circular outlet pipe*

Head $= h$	Co-efficient $= c$	Discharge in cubic feet per second	Head $= h$	Co-efficient $= c$	Discharge in cubic feet per second	Head $= h$	Co-efficient $= c$	Discharge in cubic feet per second
0 050	0 50	0 18	0 550	0 62	0 72	1 500	0 63	1 19
0 075	0 51	0 22	0 575	,	0 74	1 550	,	1 21
0 100	0 52	0 26	0 600		0 75	1 600	,,	1 23
0 125	0 53	0 29	0 650	,	0 78	1 650	,,	1 25
0 150	0 54	0 33	0 700	,,	0 81	1 700	,,	1 27
0 175	0 55	0 36	0 750	,,	0 84	1 750	,,	1 29
0 200	0 56	0 39	0 800		0 87	1 800		1 31
0 225	0 57	0 42	0 850		0 89	1 850	,	1 33
0 250	0 58	0 45	0 900	,	0 92	1 900	,,	1 34
0 275	0 59	0 48	0 950	,	0 95	1 950	,	1 36
0 300	0 60	0 51	1 000	,	0 97	2 000	,,	1 38
0 325	0 61	0 54	1 050	,	1 00	2 050	,	1 39
0 350	0 62	0 57	1 100	,,	1 02	2 100	,,	1 41
0 375	,,	0 60	1 150	,	1 04	2 150	,,	1 43
0 400	,,	0 62	1 200	,	1 07	2 200		1 44
0 425	,,	0 64	1 250	,,	1 09	2 250	,	1 46
0 450	,,	0 65	1 300	,,	1 11	2 300	,,	1 48
0 475	,	0 67	1 350	,	1 13	2 350	,	1 49
0 500	,,	0 69	1 400	,,	1 15	2 400	,,	1 51
0 525	,,	0 71	1 450	,	1 17	2 450	,,	1 52
						2 500	,	1 54

*Based on experiments by Messrs J S Beresford and W J Wilson Discharge $= c\,(0\ 1964\sqrt{2gh})$

CHAPTER VI.

WORKS.

1. **Type Plans.**—It is not easy or perhaps possible to prepare Type or Standard designs for many of the classes of works required for canals. The conditions affecting head-works and heavy drainage crossings are so variable as to preclude all but special designs, which are also necessary for all works when the formation level soils are untrustworthy. The failure of a large work on a road, or even a railway, has only a more or less local effect, and the inconvenience can quickly be overcome by temporary expedients. Moreover, on railways, the opportunities for experienced inspection are frequent, while, owing to their great length, the wide area they cover, and the heavy duties of the superior establishment employed on running canals, the inspections of particular works are necessarily made at considerable intervals of time. Moreover, the damage caused by a heavy breach in a canal is not confined to the area destroyed by the flood, but by cutting off the irrigating supply may have disastrous results on the agriculture of a large tract. Too much care cannot, therefore, be devoted to the plans of works liable to severe action, and the information regarding drainage etc., shown on the Professional and Village Maps, is quite as necessary to the designer of works as to the practical irrigator. To describe in detail all the works likely to be required on a canal in Northern India would be beyond the scope of this Manual; it will be sufficient to briefly sketch the ordinary conditions affecting the design of each class. It must be remembered that a perfect working plan cannot be drawn from theory only, it requires long experience tempered with a thorough local knowledge to design with confidence works calculated to stand the tests of time, and the enormous strains of large bodies of water passing with high velocities through, above, and below them, founded as they will be in most instances on unstable and treacherous soils.

2. **Main Weirs.**—The class of obstruction required to turn the supply from the river down the canal, will depend on the slope and nature of material composing the river bed, and the comparative volume of flood of the river. These obstructions may be divided into three main classes, which are usually distinguished in India as follows, *viz.*—(1), *Main weirs*, consisting of permanent bars across the river high enough to turn the maximum supply down the canal, but allowing of the passage of floods over them; the full height of the weir may be permanent

or a portion of it may be temporary and capable of removal during floods (2) *Complete dams*, which are properly structures with their permanent crests raised above the maximum flood levels, and provided with waste weirs and sluices for regulating the supply (3), *Temporary bunds* * consisting of either cribs filled with stone plain stone or even earthern embankments across the bed high enough to turn the full supply down the canal, and arranged so as to be more or less completely washed away by the annual floods

The term *Dam* is also very commonly applied to obstructions not permanently raised above the river bed level, but provided with piers and gates, or planks, or gates alone, and used either for total temporary obstruction, or regulation, or both.

3 **Examples of Main Weirs** —Three distinct types of main weir as usually built in Northern India are exemplified by the Narora weir on the Ganges river at the head of the Lower Ganges Canal, the Okhla weir on the Jumna river at the head of the Agra Canal, and the Paricha weir across the Betwa river at the head of the Betwa Canal (*see Plate* VII)

4 **The Narora Weir** —The Narora weir is founded on fine river sand without any admixture of hard material and as will be seen by an inspection of the cross section, when first built consisted of curtain and drop walls connected by a platform and protected by pitching above and an extensive talus below the weir crest being a masonry wall resting on the curtain and fitted with flap shutters, arranged so as to lie down on the top of the wall during floods and offer little or no obstruction to the passage of water when down, but to form, when raised and secured a water tight barrier. This weir is protected on both flanks by extensive revetments raised well above maximum high flood level, and is connected directly with the canal head and with a set of under-sluices for regulation and clearance of the canal head from river deposits This combination of crest wall, under sluices, canal head, and lateral revetments, is common to all Indian weirs, the detail of the arrangements being varied to suit different localities and circumstances. Some years after the completion of this weir it was found necessary to protect it with a puddle apron up stream to prevent sand being washed out from underneath this foundations This point is referred to in paragraph 12

5 **Height of weirs** —The height to which the weir crest can be permanently built depends on the depth of the bed of the river below its natural banks and the volume of the floods As previously noted, most Indian trough rivers have a wide "khadir," and the main stream

* 'Bund,' —Anglo vernacular for embankment

generally hugs the high table-land or "bangar" on one side,* leaving a broad stretch of low-lying and more or less marshy land on the other, this is called the khadir, and is composed of alluvium, often very sandy, but sometimes very rich and highly cultivated, though liable to be flooded. (*Fig.* 47, *Plate* IX.)

Now it is evident that an injudicious raising of the weir crest will swamp the khadir at all times, and seriously endanger the safety of the weir during floods, which would be afforded every inducement to avoid the weir, and cut a new channel for the river through the low-lying khadir. In most cases these results would follow the construction of any hard bar or weir in the bed, raised ever so little, were it not for the provision of marginal embankments and training works; but the height to which these embankments can be raised with safety is very limited, and to ensure them from injury by erosion, it is necessary to fix their alignments at a considerable distance from the river channel.

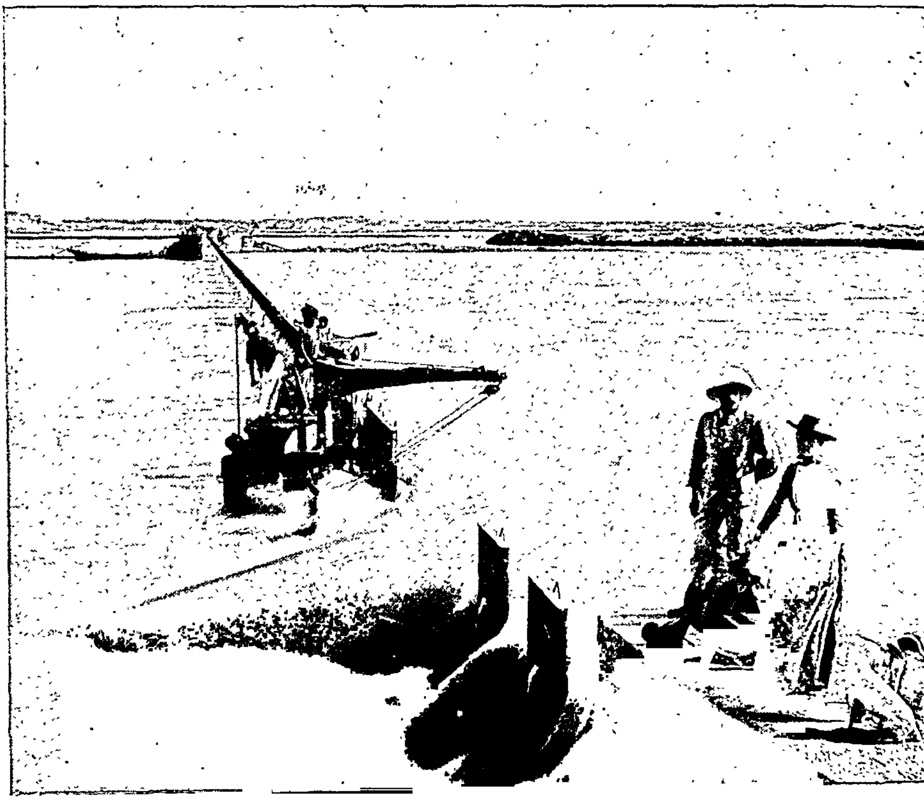
As trough rivers from their very nature always run at a considerable depth below the highlands or "bangar" (the area which it is desirable to irrigate), it is clear that the main canal must of necessity run in deep digging for some distance after leaving the river; there is thus every inducement to save expense by unduly raising the weir crest. This temptation must, however, be stoutly resisted, for although it is possible by well designed training works to more or less strengthen a badly designed weir, yet the cost of such works, if extensive, is always great: the expenditure on their maintenance a yearly recurring charge, and the instability of the works a never-ending source of anxiety to the officers directly responsible for them.

6. Drop Shutters.—The introduction of drop shutters on the crest has, to a certain extent reduced this difficulty, but not removed it, as such shutters cannot be worked in a satisfactory manner by simple hand labour for depths exceeding 2½ feet,† and no perfectly efficient design for self-acting or power-worked‡ shutters has as yet been brought forward; nor is it likely that any self-acting plan could be applied with safety to large weirs, for the results on a weir, say a mile long, of the sudden fall of all the shutters so balanced as to free themselves when the supply had reached a determined height, would be disastrous. Moreover in India the care of, and repair to elaborate machinery is both very expensive and difficult, if

* On rivers running in a southerly direction this is usually the west bank—supposed to be due to the diurnal rotation of the earth.

† The shutters are usually 3·5 feet high.

‡ An illustration of a method employed on the Chenab Canal is given here.



LIFTING SHUTTER WITH CRANE, CHENAB CANAL WEIR.

WEIR SHUTTER, CHENAB CANAL.

Photo.-Mechl. Dept., Thomason College, Roorkee.

not impossible at present, to arrange for The plans of an efficient pattern of shutter now in use are given on *Plate* VIII It will be seen that any individual shutter can be removed for repair without disturbing those adjacent, and that no piers whatever are required—this is a most important point—as piers would be certain to catch *débris* and trees floating down the stream and thus cause obstruction When for special reasons it becomes necessary to raise these shutters against a larger head of water than simple hand labour can cope with, the following method is adopted, (*see Fig* 48 *Plate IX*).

Two vertical channel irons AA supported by struts B are placed abutting against and in front of the shutters, care being taken to leave a little more than the clear space for one shutter between them They are held vertically in this position by experienced labourers while others bring up the planks CC, one plank is first held horizontally at the surface of the water rushing over the weir D, and then slowly, but steadily, pressed down until it rests on the weir in front of the shutters, once there the water pressure keeps it firm and the other planks are placed in the same manner. After two or three planks have been fixed the pressure of the water holds the vertical channel irons firm the centre shutter E can then be raised and fixed by its chain F In this manner each alternate shutter is raised, when the use of the verticals is discontinued, and the planks fixed instead in front of the raised shutters themselves to allow of the intermediate shutters being raised Depths of water up to 3 feet can thus be successfully dealt with, but the process is slow, and in the case of high velocities requires intrepid and experienced men It might be thought that the water flowing over the weir on each side would curl up in front of the planks, but this is only the case to a limited extent not enough to interfere with the raising

These shutters, first introduced by the author on the Narora Weir in 1878, have since been placed on many of the large works of a similar class in India

7. **Afflux caused by a weir** —A consideration of the various formulæ for discharge over submerged weirs will show that the flow level at the weir will not be increased by an amount equal to the actual height of the weir In heavy floods the afflux* at the Narora Weir (10 feet high) is little more than 1 foot This very small afflux may possibly be due to the form of the weir (a clear fall), as the afflux on the Okhla Weir (a rapid 10 feet high) is very much greater, sometimes 5 5 feet It is probable

* *Vide* Appendix C, giving flood levels and discharges

that a narrow bar like the Narora Weir has but a very local influence on the enormous mass of a heavy Ganges flood; at the same time its ample length compared with the discharge has certainly some effect in reducing the afflux.

Besides determining the afflux at the weir site, † it is necessary to investigate its probable extension above the weir (*vide* formula, Chapter V, paragraph 16) before finally fixing the height to which the weir may safely be raised.

8 **Saturation of low khadir land.**—When the khadir of a river liable to heavy silt-laden floods is examined, the highest land will be found close to the banks of the channels: this is due to the large sand particles thrown down by the overflow, which naturally deposits close to the main stream immediately the velocity is checked owing to the flood spreading; the surface contour of the khadir will, therefore, not be flat, but a series of depressions bordered by slightly higher lands—(see *Fig.* 49, *Plate IX*).

In the depressions AAA will be found clay beds, the results of slow deposit from the floods, checked here both by the blocked outfall and the heavy growth of jungle which covers these low swampy lands in the earlier stages of their formation before they are broken up for cultivation. Such depressions are peculiarly liable to damage by percolation, while at the same time capable of high cultivation, and giving rich crops on account of the annual replenishment the soil receives from the fine flood deposits. Care must therefore be taken not to destroy them by percolation from an undue raising of the height of the supply in the river during dry months of the year; the passage of floods over them to a moderate extent will do more good than harm as fertilizing matter is deposited on the land. It must of course be understood that it will be quite impossible to construct a weir under ordinary conditions without

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† *The formulæ most used in the N.-W. Provinces are as follows:*—

For clear Falls, $D = 3\cdot36 \times L \left\{ \sqrt{(h + 0\cdot04u^2)} - {}^{3}\sqrt{(0\cdot04u^2)^3} \right\}$

„ submerged Falls, $D = 5\cdot04 \times L \left\{ d_2 \sqrt{d_1 + 0\cdot04u} + \tfrac{2}{3}\sqrt{(d_1 + 0\cdot04u^2)^3} - \tfrac{2}{3}\sqrt{(0\cdot04u^2)^2} \right.$

or $D = 8\cdot5 \times L\, d_1\sqrt{d_1 + 0\cdot035u^2} + 5 \times L \times d_2\sqrt{d_3 + 0\cdot02u^2}$

Where D = discharge in cubic feet per second.

L = length of weir in feet.

h = depth from normal surface of water above weir to top of weir in feet.

u = velocity of approach of water to weir in feet per second.

d_1 = height of fall of water in feet, *i.e.*, difference between normal surfaces above and below weir.

d_2 = depth of top of weir below normal surface below weir in feet.

injuring some land, the evils can, however, be kept within moderate limits by a careful study of and attention to, the contours of the country, and in time the annual floods, if utilized judiciously in warping operations will, of themselves, raise the low depressions, which can then be put under plantations or let out for cultivation

9 **Reservoir Dams** —These restrictions as to height of crest do not apply to cases where the conformation of the river valley admits of the weir being utilized as the retaining dam of a reservoir to husband the supply In this case the height will depend on the contour of the reservoir valley, and the facilities afforded by the site for the weir, which must be located in a gorge forming the outlet to a valley, to render the project economically feasible The Paricha weir on the Betwa river is an example of this class of work. The floods passing over the Paricha weir occasionally amount to 620,000* cuses.

10 **Length of Weirs** —The length of a weir is determined by the magnitude of the floods The height of the weir wall being known, and the maximum depth on the crest fixed in accordance with the considerations mentioned above, the length should be simply that sufficient to discharge the maximum flood It is, however, not by any means a simple matter to determine the amount of the greatest flood ever passed down an Indian river Canal weirs are generally situated high up near the hills, where no permanent bridges or other works likely to supply a record exist Gauge observations are rarely carried on until a short time prior to the institution of the project, and calculations from recorded rainfall, if such records exist, are extremely liable to error, moreover the periodical occurrence of extraordinary rainfall causing abnormal floods at long intervals is a marked feature of Indian meteorology. Thus on the Kali Nadi in the United Provinces, (which has a maximum normal flood discharge of 26 317 cusecs) on the 2nd October, 1884, 44,000 cusecs passed down, *followed on the 17th July, the next year, by* 130,000† cusecs These floods were absolutely unprecedented, and no experience could have foreseen or anticipated them, the engineer is therefore, compelled to trust more or less to local tradition for his record of the highest flood marks, and to theory for the determination of the actual discharge from the cross section and slope of the river By enquiring from a large number of individuals, comparing results, and exercising a wise discretion,

* Calculated maximum = 750 000 Flood on 6th August, 1884 = 615,789, with nearly 18·0 feet depth on crest

† The catchment basin of the Kali Nadi = 2,377 square miles, therefore run off = 55 cubic feet per square mile

wing wall and revetment low, and as boulder or clay sites can generally be found for these minor works, the danger of the weirs being turned by over-spill is small and easily remedied if it occurs anywhere but immediately adjoining the work

11. Flood Spill Weirs —The flood spill weirs referred to above should be located where they will have no tendency to cause a draw from the main stream. In deserted channels well coated with clay* and grass, rejoining the parent river at a considerable distance below the main weir, the crest may be fixed at or about normal flood level. A number of small works will generally be found easier to manage than one large one, as the latter in a very heavy flood is liable to develop too defined a channel These weirs require very careful protection with pitching both above, below, and on the flanks, but inspection is easy, and repairs can be economically carried out, as the works are nearly always dry.

These works are also beneficial in an agricultural sense, as many khadir lands become unproductive if deprived altogether of the deposits from flood spills. The designs for these works ought to be as simple as possible, a concrete bar faced with masonry and provided with deep curtain and drop walls will suit most situations, the flank revetments being taken well into the marginal embankments Regulating arrangements are unnecessary and objectionable

12 Details of Main Weir Design —The length of the weir and the height of the crest being finally determined the details of the design can be worked out to suit the locality, soil etc *A weir proper consists of a* crest wall and a floor below, suitably protected from injury by the forces it will have to withstand when in work, both in floods and when the river is low and the canal full.

The three main forces tending to destroy a weir are—

(i) *rafts or trees floating down the river*,

(ii) the action of the water approaching, falling over, and leaving the weir in floods,

(iii) the creep or underground scour of water caused by the heading up of the water above the weir, and the fall in level below in times *of a low river* and a high demand *for irrigation*

The first destructive force mentioned is easily counteracted by making the crest wall massive enough to withstand the blows or strain to which it may be subjected, or by providing arrangements to catch and remove *floating débris before* it can reach the weir. The action of the floods on

* *When the main stream once leaves a channel, the slow passage of spills down it over a* series of years, generally coats it with a fine hard clay deposit

a weir is provided against by spurs and groynes which lead the floods on and off the weir in as favourable a direction as possible, so as to avoid cross currents, and by using large quantities of heavy material in the form of loose curtains and aprons below and above the weir, so as to prevent the light sandy bed of the river being eroded by scour.

It will be seen that the first two destructive actions can be simply enough provided against, although they often involve considerable expenditure, and always require experience in the arrangement of proper training works. The third main injurious action, "creep", is much more difficult to counteract; its occurrence, particularly in the earlier stage, is not easy of detection, and its results are both disastrous and very troublesome to remedy. The means to be adopted to provide against creep will be specially referred to in describing the details of canal works.

The case of built structures as distinguished from loose stone weirs will be first dealt with. On boulder or strong clay soils, solid concrete or rubble stone foundations will be most suitable, and can usually be laid without any special precautions, except those required for the removal of water, but in sand it will be found necessary to use square or oblong well blocks owing to the difficulty of excavating sand in water. These blocks can be used either as foundations to support the weir structure, or as a coffer-dam within which it can be constructed on a solid concrete base.

When well blocks were originally used as the foundations of weirs, it was presumed that with piles driven in the intervals, they would form a continuous barrier to the creep of water from above the weir, but as it is in practice impossible to ensure perfectly vertical sinking (*see Fig.* 50, *Plate* IX.), it is evident there can be no advantage in this respect, and the best method of getting in the foundations is to use the blocks as coffer-dams. Even when used as coffer-dams the lines of blocks should be filled with concrete, and left as part of the permanent structure to which they will form valuable additions as curtain and drop walls for the protection of the weir from injury by local erosion of the river bed in its vicinity.

The floor below the crest of the weir should be designed of a width and strength sufficient to withstand the turbulent action of the water falling over the crest wall, and be heavy and water-tight enough to resist the upward pressure of the water held up above the weir. As it will be shown further on that this latter force is more or less under control, it will be sufficient for the Engineer at this stage to decide on the width necessary for the weir floor on the first consideration only, and if the training works are properly designed, the heavy action of the water falling over

a weir should be confined within a distance of from three to four times the height of the crest wall The floor and crest wall may preferably be designed on a broad solid concrete base, of the best masonry, protected on the surface by massive stonework Experience shows that a broad heavy mass, with a horizontal base resting on pure sand, affords considerable resistance to creep , corrugations on the base of the concrete would increase the resistance, but probably not to an extent sufficient to compensate for the expense and difficulty of constructing them efficiently under a heavy head of water in the foundation pit

One detail of execution requires special notice in connection with all works constructed on concrete foundations to *obstruct* or hold up water , this is the necessity of ensuring that the lowest as well as the upper layers of the mass of concrete contain a proper amount of mortar ; nothing can be more injurious to the creep resisting power of a mass of *concrete* than a substratum of porous ballast *resting on* sand.

On long weirs cross lines of blocks are required to form compartments of a manageable size These blocks should not be carried up right through the concrete, as vertical junctions of masonry and concrete are liable to open, and leave passages for springs. The difficulties of making satisfactory joints between concrete and masonry are so great, and the effects of unequal settlement so disastrous, that on these grounds alone it is preferable to use the blocks simply as outside coffer dams, and to found works on homogeneous masses of concrete laid inside them instead of on them. This does not interfere with their utility as a protection against scour, and permits of the use of inferior material in the walls and hearting of the blocks. Experiments made during the construction of the great Nadrai Aqueduct of the Lower Ganges Canal have shown that the most satisfactory material for *hearting* permanent blocks *in* water is sand concrete the exact proportions suitable must be determined on the spot by experiment with the qualities of lime and sand available but the material will in any case be cheap enough to render its extended use financially possible

In order to show how a weir or any work erected for holding up water on a porous sandy foundation can be efficiently protected from destruction by " creep," it is necessary to consider how this action takes place, and in view of the importance of this question to Canal Engineers the report of the experiments on the friction of water passing through sand, has been reprinted as Appendix VI

For all practical purposes of design, it will be sufficient here to say that the resultant upward pressures of water headed up above a work,

will act under that work with forces in the direct proportion of their distances from the point of application to their points of exit.

The application of this principle to the protection of a weir will be quite clear if the practice of building floors with a wide grouted and impermeable talus below the crest be compared with the system of up-stream water-tight aprons as recommended in the Report, Appendix VII.

An inspection of *Figs.* 51 and 52, *Plate* IX, in which the worst case is taken, *i.e.* when all the water in the river is going into the canal, will show the great difference there is in the upward pressures P and P′ at any given point on the weir floor or talus. It will easily be understood that there are two actions to be guarded against, *viz.* the tendency of the head of water above the weir to blow out the sand directly from under the masonry work in a longitudinal direction, and secondly, the carrying up of sand from below with springs through minute cracks or crevices in the masonry work or grouted pitching. In practice, however, the first action only takes place under broad weirs, when local springs, carrying up sand from pockets below, have cut up the original great width into isolated portions which can be blown through one after the other.

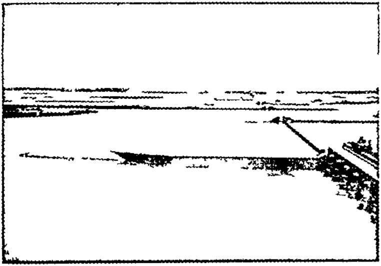
In each system the length DC is taken as impermeable, but a grouted talus, such as shown in *Fig.* 51, can rarely be kept perfectly free from springs, as it is liable to slight settlement, and wherever a spring acts, except quite close to C, where the pressures are low, sand will be carried up by the spring water causing a hollow below, and more settlement.

In plain pitching dangerous springs bringing up sand cannot act; the surface open for the emission of water is practically unlimited, and it will be at once understood that a spring cannot carry up sand with it unless its exit or channel be sufficiently confined to induce the necessary velocity.

In *Fig.* 52 the length of puddle from D to the weir crest is also apparently subject to powerful upward pressures, but these are more than counteracted by the weight of the water resting on its surface. In *Fig.* 51, on the contrary, there may be little or no water pressing down the material of the weir and talus, and the water the material is immersed in reduces its effective weight by 62lbs. per cubic foot.

The sheet piled terminal at D (*Fig.* 52 is primarily a protection from scour to the puddle apron, but it also tends to reduce the danger of longitudinal creep in an efficient manner, by reducing the head.

It will be seen now that when the quality of the sand on which it is proposed to found a weir is known, by using the data given in



UNDER SLUICES AND WEIR CHENAB CANAL

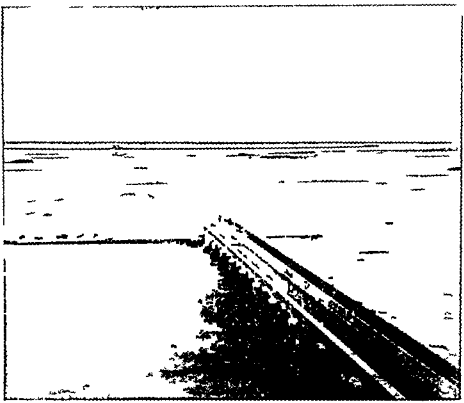


Photo.-Mechl Dept. Thomason Co ege, Roorkee.

CHENAB CANAL WE R AND UNDER SLUICES

Flood of 16th August 1893.

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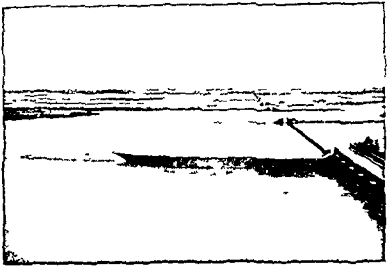
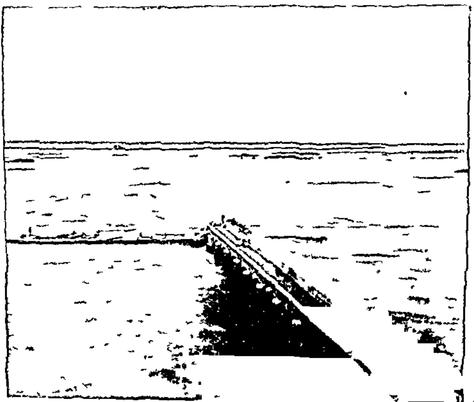


UNDER SLUICES AND WEIR CHENAB CANAL



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CHENAB CANAL WEIR AND UNDER SLUICES

Flood of 16th August 1892.

Appendix VII, or data specially arrived at by similar experiments, the proper dimensions *for constructing* a *weir* can be accurately calculated, and the work constructed with confidence in its ultimate stability.

Since the issue of the Report, Appendix VII, the Khanki weir of the Chenab Canal, and the Narora weir of the Lower Ganges Canal (*see Plate* VII) have been repaired in accordance with the conclusions arrived at Both these great works had been seriously injured by creep, which in the latter case had apparently acted for a long series of years before causing noticeable injury

Similar puddle aprons protected by thin layers of concrete were laid by the author above the Jaoli Falls of the Ganges Canal, the Gopalpur Regulator of the Lower Ganges Canal, and the Gangan Regulator of the Nehtor Canal many years ago—all these works had been very seriously injured by creep, and were in a most unstable condition The aprons have answered perfectly well, and the works, though subject to heavy varying heads of water, have given no trouble since This system of protection was invented by Col Western, *C M G*, *R E*, the officer who afterwards so successfully repaired the Nile Barrage

13 **Under-Sluices**—Under sluices are required in a weir to keep the canal head free from river deposits, as a help to the training of both the flood and cold weather supplies of the river, and for minor regulation of supply to avoid the necessity *of frequently raising* and lowering the weir shutters The canal head *being of necessity situated* on one flank of the weir, these sluices, to *fulfil their primary duty* must be placed in a corresponding position—*this is not at all conducive to their* action as a *training medium, except in so far as it allows of their being used to attract* the *cold* weather channel *of* the river to the canal head But although it is probable that the scouring sluices *from* the canal below the head might be made to *efficiently* perform this latter *duty* and *even perhaps* also to clear the head from silt there would still remain an *almost* insurmountable difficulty to moving the position of the under sluices *from* the flanks, *viz* the practical impossibility of working them *during* floods, as the length of the larger weirs and the objections to many small piers preclude the idea of a bridge, except when a railway or road *cross ing* at the same point admits of the combination of the *two works* *The* main objection to flank sluices is that they maintain the deep flood channel of the river along the flank instead of the centre of the stream, thereby drawing the floods on to that bank and necessitating extensive training works to protect the canal channel from destruction Careful and judicious working of the sluices may, to a certain extent, alleviate this

evil, but protective works will always be necessary, unless the canal channel can be aligned so as to run at a considerable distance from the river; this is rarely possible without entering the bangar or high table-land in deep digging.

The advantages of maintaining a deep channel in the centre of the river are so great, that a short length of the crest wall in the centre of the weir might, with advantage, be fitted with a double set of grooves and planks or shutters (*see Fig.* 53, *Plate* IX) to be removed either before or for a short time after the floods, but while the river was still carrying a supply in excess of canal requirements. These secondary sluices would enable a centre river channel to be kept open which would help to properly direct the next season's floods. The diagrams (*Fig.* 54, *Plate* IX) show the bad results of flank and advantages of centre channels.

The floor of the under-sluices should be at least on the level of the normal bed of river, and not less than 2 feet below the floor of the canal head. It may be depressed below the river bed without objection, as the sluices invariably cause a retrogression of level in the bed of the river below. Indeed the floor level may be fixed considerably lower than the river bed if the foundations can be got in with economy, as the remedies to heavy retrogression below sluices are always expensive. If the foundation difficulties are excessive, necessitating the floor being built at bed level, provision should be made for a massive talus consisting of a series of bars with gently decreasing surface levels, connected by layers of pitching (*see Fig.* 55, *Plate* X).

These bars, which may be composed of crib-work, masonry well blocks or heavy dry stone-work, can be constructed as retrogression proceeds, and are necessary to keep at a distance from the sluices the deep hole which is always formed in the river bed below by the rush of water through the sluices, unimpeded as it generally will be by dead water below.

It may be mentioned here that the deep holes which so frequently occur below the weir and sluices, more particularly the latter, are formed, as a rule, by the low cold weather supplies or during falling floods, and not by the maximum discharges of high supplies. This is due not only to the absence of back-water, but also to the greater scouring power of clear compared with heavily silt-laden water.

The inevitable deep hole below the sluices must be accepted when the river bed is composed of sand or any friable material, but it need not be considered dangerous; indeed it will be advantageous as providing a cushion of water if kept at a distance from the sluices and paved with hard material.

These talus bars require splayed connections at their *extremities* with the down stream wing walls or revetments of the sluices, and if continued below them, should be carried sloping up the river bank on one side, and the sluice down stream groyne on the other.

The down-stream wing walls of the sluices are shown in *Fig* 56 *Plate* X, parallel with the stream at right angles to the weir line It was formerly the custom to splay these walls, but the dead water thus held up is found to cause reflex action, and also to throw the current to one side, thus eroding the river banks below, besides concentrating scour on the centre of the channel (*see Fig* 57, *Plate* X).

The surface of the water as it issues below the sluices under pressure is not level, it assumes the form shown in *Fig* 58, *Plate* X, and should be kept within a channel with firm sides and bed until it has regained the normal level and direction of the supply below in the river The endeavours of the supply from A to fill the hollow B is mainly the cause of the cross currents below the sluices, and this tendency is aggravated by the splay of the wing walls it is, therefore, best to confine the discharge within parallel walls (which also increase the depth of the back water) until it has attained a regimen, when it may be returned to the main river without fear of causing injury to the banks It would appear the natural course to incline both sluice walls towards the centre of the main river so as to correspond with the splay of the canal head, in order to assist the result shown previously as attainable by the use of centre sluices, but this would cause similar ill effects to the direction of the weir flood supply, and the necessary slight inclination to the direction of the discharge can easily be given by a few small groynes fixed slightly overlapping each other on the river bank below.

The distance of the point A below the sluices depends on the head of pressure and depth of back-water. It will, however, not be safe as a rule for large sluices to make the masonry wing-walls less in length than ten times maximum possible head, and the down stream groyne in continuation of the masonry wing wall should be at least as long again a groyne of crib and stone work or loose stone may here and above the weir be substituted for a masonry wall founded on deep wells, simply to save expense, and as these works are unconnected with the block of the sluices, slight settlements or injuries to them can be quickly and cheaply repaired.

The groyne above the weir with its upper surface like that of the one below, well above maximum flood level, is intended to prevent longitudinal scour parallel to the upper face of the weir (*see* dotted arrow, *Fig* 56,

Plate X) This scour would be induced if this groyne did not exist by the varying surface of the supply immediately above the sluices compared with that above the weir. When the weir is a very long one, particularly if the main river approach is divided up by islands into several channels, similar groynes at intervals of about 250 feet should be provided for its protection. These groynes will effectually stop the formation of islands immediately above the weir, and prevent parallel scour; they will also give great facilities for training and directing the course of the river by means of the weir shutters, which can be opened or closed in any desired compartment.

The length of up-stream groynes should depend on the nature of the river and the direction in which the cold weather channel approaches the canal head. As they can be lengthened at any time, this dimension for original construction is not a matter of great moment, it will be sufficient to estimate them of a length equal to the width of the proposed compartment in the weir.

The cross section of those groynes may be a trapezoid, with side slopes of 2 to 1. The ends or noses should be sloped off at 1 in 10 until they meet the level of the river bed (*see Fig.* 59, *Plate* X). They are easily founded by utilizing the scouring power of the cold weather supply which should be directed on them during building. The clear water will scour away the sand in front of the stone as the latter is advanced, and this economical method of construction will generally give just the proper depth of foundation which, for estimation, may be taken at one-third of the height of the groyne above bed level, no allowance being necessary for excavation or pumping (*Fig.* 60, *Plate* X).

The hearting of these groynes may be made of sand with advantage, as this reduces expense and makes the groynes water-tight.

The provision of sufficient pitching on the bed of the pocket above the sluices must not be neglected. Owing to the presence of the up-stream groyne, there will be very little of that boiling action in the water above the sluices, so common and destructive to the bed, when the supply reaches from different directions; nevertheless, the velocity will be considerable in high floods, and when the sluices are used for scouring, a paving all over is required close to the sluices and canal head with parallel bars of hard material as far as the groyne extends: a most excellent protection above sluices is the puddle and concrete apron recommended for the weir.

To fulfil all requisites, under-sluices should be calculated to discharge the maximum snow water volume of the river with water surface up

stream, level with the top of the weir, so as to enable the latter to be laid dry at any time except during floods.

If the sluices are built on a mass of concrete laid inside a well coffer-dam as recommended for the weir, their foundation will differ in stability from that of the wing walls for which this system would be both unsuitable and too expensive Deep well blocks form the best foundation for all revetments, but it will be advisable to avoid bonding the superstructure of the different systems together, as unequal settlement is certain to occur. Unbonded vertical joints will prevent many unsightly cracks, and leakage can be obstructed by tenon joints (*Fig* 61, *Plate* X)

The superstructure of under sluices consist of a floor, piers with bays fitted with gates between them, and a roadway of masonry arches, or girders, arranged to carry the gate lifts. The floor must be solid to bear without injury the blow of the falling gates and the pressure of the falling water, the surface is usually of hard stone, to resist the great erosive power of the silt laden water passing under the gates with a high velocity

The piers are generally fitted with a double set of cast or wrought iron grooves The down stream set for the gates and the up-stream for planks to be used in case of accident to the gates, for the purpose of assisting in their closure, or to remove *débris* caught under them (*see Fig* 62, *Plate* XX) The width of bay usually accepted as most efficient at present is 6 to 8 feet this narrow width, though it reduces the power required to work the sluices, is liable to cause obstruction in rivers which carry large trees or much floating *débris* during floods, for which a width less than 20 feet will not be found sufficient. For the New Head works, Ganges canal, above Hardwar, 6 bays of 50′ each have been given, to allow of small trees getting through Every alternate pier projects, to turn trees more than 50′ long and coming broad side on

In sluices with a large number of bays, abutment piers at intervals will be found advantageous, in case of accident they will localize the damage. In India lift gates are necessarily of simple design, as their care and working must be left to uneducated men, for large works they are now always built of iron, and sometimes fitted with anti friction gear, but the lifting apparatus should be powerful enough to be able to dispense, if necessary, with this relief. Arrangements are also required to suspend the gate after lifting at any particular height above the floor It would be useless here to give particular samples of gates and apparatus as improvements are constantly being made

Various systems of lifting apparatus are employed from the simple windlass to patent crab winches or screw gear. As it is always necessary

to provide for raising the gates clear of any possible high flood level, overhead masonry or iron ways will generally be required. High masonry superstructures on works like under-sluices liable to heavy action are, however, objectionable, as they are very likely to develop cracks from unequal settlement, and it is also difficult to make such high buildings architecturally harmonize with the rest of the works without going to considerable expense; and the simplest and neatest method is to combine the high lift with the gear carriage, and to arrange a neat iron superstructure for suspension alone. The motive power hitherto used has generally been manual labour, but turbines fixed on one flank could easily be adapted to this purpose.

For reservoir dams where the sluices partake of the nature of culverts and are often totally immersed, screw lifts are almost a necessity; such sluices are subject to great wear, owing to the high head, and are very difficult to repair. As the permanent supply from these works is always moderate in amount, it appears possible to take the irrigating supply out by large syphons which would enable low level sluices to be altogether dispensed with. When it is necessary to provide very wide and high openings for under-sluices, the power required to lift the gates may be greatly reduced by building the latter in sections: thus, a gate 20 feet wide and 16 feet high might be divided into four sections, each 4 feet high and 20 feet wide, each section being arranged so that when it has been lifted say 6 inches or 1 foot, the one below follows it. If after raising the upper sections of all the gates, a short period is allowed to elapse for the water headed up above the gates to escape through the openings, the pressure on the gates will be reduced, and the lower sections can be raised with comparative ease. This system is specially adapted for reservoir dams when the water of streams with a small cold weather discharge is headed up to a considerable height. It is also particularly suited to situations where it is important to avoid silting in channels below by taking off the comparatively clear surface water instead of the silt or shingle-laden bed stream. A plan of gates on this system is given in *Plate* VIII. These regulating gates are also suitable for canal and distributary heads.

A fish ladder is an indispensable adjunct to a weir, and should be placed so as to benefit by the rush through the under-sluices, as a rule the only water passage for the greater part of the year. At all the large Indian weirs immense numbers of fish collect when the supplies in the rivers are low, and the preservation of such a valuable food reserve should

certainly be worthy of the best attention of the projector of works intended directly to reduce the danger of famine

14 **The Weir talus.**—The extent of the talus required to preserve the main block of the weir from injury will depend in a great measure on the outline of the overfall Good examples of both the vertical drop and sloping outfall are available in Northern India, and the superiority of the former is now clearly established, for it undoubtedly reduces the afflux, and consequently the injurious results of heavy floods to a minimum Indeed, it would appear that when a vast body of water is moving down a river with the velocity and momentum due to the slope of the bed, the main effect of a thin wall of moderate height intercepting it, is to cause a momentary acceleration of the velocity over the reduced section, combined with a slight afflux or rise in surface above the weir, and a temporary disorganization of the direction of the currents In comparison with this the effect of a long sloping outfall is most marked the existing regimen of the flood is broken up, and the talus in a great measure has to bear the friction and pressure resulting from the partial destruction of the accumulated velocity. The flood again in its attempts to regain a regimen corresponding to the slope of bed below the weir, is very likely to cause local injury to the banks of the river and the works constructed to protect them *(Fig 63, Plate X)*.

The greatest strain on the talus is when the flood is first rising,—particularly if it is sudden and the bed above obstructed with islands for the upper channel will then fill quickly, and the fall over the weir be heavy and unobstructed by back water in the slowly filling channel below

Even with an extensive talus deep holes will always be found below sloping weirs it is probable however, that these do not exist during the passage of large volumes, but are the result of low supplies and falling floods The advantages of long perpendicular groynes above the weir have already been noticed and there is no doubt but that they are even more necessary below The function of the up-stream groynes is to direct the flood properly on to the weir, down stream groynes above high level are required to control it until re adjusted to the regimen corresponding to the slope of the river bed, and recovered from the disturbance caused by the interference of the weir Very slight action beyond the simple water pressure due to differences in the level of the surrounding flood water, need be anticipated on these walls or groynes, which can consequently be built of a comparatively weak section and their spacing and position on the weir plan may well correspond with that of the upstream groynes The necessity for their construction will be at once

understood from a glance at the diagram (*Fig.* 64, *Plate* XI), which represents the currents often observable below a long weir during heavy floods. The currents rushing back in the direction of the weir crest are due to the natural tendency of the high water at A to fill the hollow at B: the eddies thus formed cause local scour and the deposition of sand banks, and the normal direction of the flood is destroyed. The walls as proposed (*see* dotted lines in *Fig.* 64), by preventing lateral spread, will counteract this tendency of the flood to swirl, and when the walls are continued for a short distance beyond the point where the water surface attains its normal level (*see* A, *Fig.* 64), they will return to the flood its proper direction which was temporarily lost from the interference of the weir.

A practical example substantiating this theory may well be given. The Machua Weir on the Ganges Canal has a short length of crest compared with the supply often passed over it. Before the revetments AA′ (*Fig.* 65, *Plate* XI) were built, the currents followed the courses shown by the arrows, and navigation was carried on with extreme danger and difficulty, the hole below the talus was about 19 feet deep.

The construction of the parallel revetments not only stopped the reflex currents, but reduced the depth of the scour below the talus to about 10 feet. This was quite in accordance with the well known fact that swirls have great scouring power compared with direct currents of equal velocity.

The talus proper of the weir should certainly extend beyond the point at which the water below the weir regains its normal height and velocity. It is best constructed of three distinct qualities (*see Fig,* 66, *Plate* XI) viz.—

A, of considerable thickness, faced either with large blocks of stone or with crib work; a curtain wall is usually provided.

B, of loose stone less in thickness than A, but still massive, and protected from removal by a row of sheet or pole piling.

C, the curtain of loose stone; the settlement of this length as a facing to the hole below the talus is anticipated.

No weir, however massive, can be considered safe with an insufficient talus; no expense should, therefore, be spared in perfecting this portion of the weir. The actual length required depends on so many varying conditions that a general rule is not possible, but three or four times the width of the weir floor will be sufficient in most cases.

In addition to the talus or curtain below the weir a loose stone apron is required above it to protect the river bed from injurious erosion; the dimensions of this apron can be considerably reduced if up-stream groynes are provided.

15. Revetments.—Unless the weir provides for the supply of a canal on each bank of the river, a revetment will be required on the flank opposite to the canal head This being simply a terminal can be designed to suit the general architectural features of the whole structure, but care should be taken to put in very deep and strong foundations, and to raise the walls well above high water level. An allowance of 5 feet above *maximum floods is necessary for all revetments on large rivers*, the down stream wing wall should, like that of the sluices be at right angles to the weir, and the river bank above stream will require protection from erosion if exposed to action.

The river wall or revetment above the canal head should be extensive and well founded, as it will be exposed to the action of the stream drawn towards the head by the sluices. An apron of crib work filled with boulders of stone is a useful safeguard; when the soil is gravelly or good clay, considerable expense in foundations may be saved by double walls connected by a floor (*vide Fig* 67, *Plate* XI).

The provision of weep-holes or other avenues for the escape of sub soil *water from behind revetments should never be omitted*

16 Flood spill embankments—Notice has been taken previously of the great width of the khadir and its want of elevation compared with that of maximum floods, also to the existence of numerous old and more or less partially abandoned river channels Seldom indeed will it be possible to find a site for a weir so naturally situated as not to require protection from spill round the flanks On the canal side this will usually be given by the channel embankments connected with the high bangar, but on the opposite flank many miles of low lying khadir are almost certain to intervene between the terminal revetment and the nearest lands well above the calculated high water mark, due to the construction of the weir., and an embankment is obviously necessary to connect the revetment with these lands Now in aligning this bank two dangers have to be avoided, *first*, that of placing it too near the river which would endanger its existence and prevent the flood spreading sufficiently, causing an injurious depth on the embankment, and *secondly*, that of aligning so that it will be liable to act as a reservoir, intercepting the floods, which in this latter case would be certain to head up and thus destroy it The provision of spill weirs in the marginal embankment has been advocated, but these should be placed so as to act simply as reliefs to the flood, where such relief is really necessary or advantageous The proper alignment for the marginal embankment is therefore one starting from the flank revetment and slowly but steadily moving away from the river, following, if possible,

a natural watershed; great care being taken when crossing old channels to be certain that the flood spill passing down them has a free exit back to the main river from some point above and near the crossing of the embankment. It is excellent plan to make these banks, which may often extend to several miles in length, wide enough for a driving roadway, and to plant broad belts of suitable trees on the level ground at each side. The roadway facilitates inspection, and the trees afford grateful shade, and are a useful protection against scour, and available at all times for spars or other repairs. Where likely to be exposed to scour, the embankment should be protected by cross groynes, and it may here be noted that it is necessary to specify that all the earth for the bank be taken from the river side, in long parallel unconnected borrow pits (*See Fig*, 68, *Plate* XI).

These excavations will be filled up in the course of years by the river silt, and do not increase the head on the bank during floods as outside pits would.

After some years the general surface of the country between the embankment and the river will be found to rise from the slow but steady flood deposits; this tendency should be encouraged by the construction of warping cuts from the river to local hollows, care being taken not to draw the main stream from its proper course towards the embankment. The broad stretches of khadir land lying beyond and outside the embankment are very liable to lose their rich fertility when deprived of the annual deposits and washing formerly given to them by the river floods, Flood spill weirs, if constructed, will partially remedy this, and there will be no danger in constructing special culverts for the same purpose if they are well founded and protected from injurious action. It must be borne in mind that the function of the flood embankment is to control the spills of the river, and this does not of necessity include shutting them out altogether, though not infrequently this last point is lost sight of.

17. **The Canal Head.**—The splay of the canal head with a perpendicular to the centre line of the weir, ought not to exceed 30°. Skew heads are very expensive to build and complicate the regulating machinery; this small splay is useful in giving a good direction to the entering currents—a greater splay than 30° would cause silting up of some of the bays.

The lower wings can either be parallel or splayed to suit the width of channel; the velocity of the main canal being slow compared to that below the sluices, there should not be much action below the head, and although a talus is necessary, yet it need not be designed on the massive proportions required for the weir.

It is well known that a very slight head will suffice to force a supply through a comparatively small narrow opening into a channel of large dimensions below, yet when it is remembered that this increase of head will mean a fixed increment on the whole length of the weir, which may be a mile, it will be seen that the best, and probably also the most economical policy, will be to give a large area to the canal head

If the canal is navigable and a river lock is provided, the allowance made may be reduced by the width of the lock head bay, as the lock gates can always be opened full when the canal is running without any-fall into it .

To allow of easy regulation the bays of the head should not exceed 6 feet in width for smaller branch canals For main canals small or of big volume, 20′ spans with roller gates are commonly used The general design of the head may well correspond with that of the under-sluices, but the gates are only required to lift a foot or two above full supply unless regulating gates to admit of surface, i e, silt free water being admitted during floods, are considered necessary (*see Fig* 69, *Plate* XI). When plain gates only are provided, a curtain wall is necessary to shut out floods from the canal, on small works, sleepers or planks, above the gates, are often used for this purpose

For small works, where the flood level is very high compared with the depth in the canal, a separate high level gate is very convenient (*see Fig* 70, *Plate* XI) For big canals a breast wall is now frequently used

The canal head is generally provided with a roadway and utilized as the head public bridge on the canal, but the practice is open to some objection, as accidents might occur from interference with the regulating arrangements

18 **The River Lock.**—The river lock must take off at an acute angle to the river revetment (*see Fig* 71, *Plate* XI), in order to allow boats to enter without danger in a rapid current, this necessitates a pocket above the upper gates,* which will silt up unless the lock is provided with powerful scouring sluices

The upper gates should be calculated to stand the pressure due to maximum floods, and have grooves in front for the reception of beams to shut off the floods in case of accident

A lift or swing-bridge will be required where the roadway crosses the lock to allow of high laden boats entering the canal during high supplies. Lockage into the river below the weir is rarely required, as the

* Skew gates in a line with the revetment might be constructed but the expense would be quite out of proportion with the moderate demand for navigation facilities usually current on canals

canal will probably take up the lower river navigation, and during periods of short supply the river bed below will be practically dry. During the floods, rafts can pass the weir over the crest where the afflux is slight. If, however, navigation below the weir is considered desirable, the lower lock can be usefully combined with a dry dock, by widening it, and providing benches or slips at a level below high and above low supply.

19. **Gauges.**—The wave or constant fluctuation in the surface of large bodies of water, or even small volumes when flowing rapidly, is great enough to preclude accurate reading of the levels being taken directly on a gauge fixed in the stream. The difficulty is, however, easily surmounted by providing what are called still-water gauges.

These are simply ordinary gauges fixed in a well or cistern, the supply in which communicates with the river or canal water outside through a small hole or pipe half to one-third of an inch in diameter. The level of the water inside the cistern will be found to remain steady at the mean level of the undulating surface outside, and readings can be made on the gauge to any desired degree of accuracy. On large works it would appear desirable to record the variations in the mean level automatically by an indicator. Regarding undulations in the supply passing through a regulator, such as the canal head, etc., there is a curious and as yet unexplained wave, which periodically at short intervals, rises and falls in each alternate bay of all regulators with an even number of bays; when the number of bays is odd this wave action is not noticeable. Gauges are required at the following points on head-works:

Above the Weir.—Zero at crest level. Gauge to be fixed a little above the point where the water surface begins to drop over the weir. A gauge on each flank of a long weir is necessary, as there is frequently a considerable difference in level between these points.

Below the Weir.—Zero at floor level. Gauge to be fixed a little below the point where the supply attains its normal level after passing the weir.

Below the Canal head.—Zero at bed level for the point where gauge is fixed, which should be at a convenient position for taking discharges of the volume.

These are all the gauges absolutely necessary for regulation, but it will be well also to fix gauges at intervals for some miles up and down important rivers and above and below large groynes The record of these gauges will be a valuable guide to training operations on the river Gauges can be recorded either by reduced levels or in feet and decimals —both systems have advantages. If it can be managed so that the zeros of gauges are even feet, the reduced level system should undoubtedly be chosen

20. Relative advantages of masonry and loose stone Weirs - A glance at the Cross Sections of the Okhla and Narora Weirs will show that the principles of the two designs are totally different, the former being merely a conglomeration of loose stones laid on the bed of the river bounded as it were by a few long walls of masonry without any foundations while on the latter designs all possible ingenuity has been expended to provide against injury from scour or retrogression The Okhla is the Madras type of weir, and its stability would be doubtful in a river carrying very pure sand and *little clay in suspension for experience* shows that the apparently loose stone has to become closely cemented together with clay silt before it acquires stability The section shows the stone lying on the normal level of the river bed but in reality it occupies a much lower level, for weirs of this type can only be constructed by degrees additional layers of stone being placed year by year evenly over the whole length of the weir until the full height has been reached During this process, after the floods, great depressions and hollows are formed in the work due to the stones sinking as the water creep cuts out the sand below them, at length a point is reached, when the depth and irregularity of the lower surface of the weir is sufficient to arrest this action

The actual quantity of material required for a work of this class is therefore far greater than that shown by the normal section, and construction will only be economically possible when large quantities of stone are available close to the site As previously noted an increase in afflux over that which would be given by a thin wall must be expected, and the junctions with the solid masonry of the revetments and sluices will always require careful watching and protection, at the same time *it must be admitted that all needful requirements being to hand this* type of weir is generally a very cheap one to construct, requiring but little plant or expensive supervision

The remarks made regarding sluices and other details of masonry weirs apply equally to loose stone weirs

21. Temporary Head Works.—A general description of boulder head-works has been given already, but it is here necessary to enter on a few details of the construction of the different works.

The simplest form of temporary head-work is an embankment across the main stream with water-courses leading away directly from the river banks; an escape channel through high land round the flank of the embankment is usually provided to prevent breaches during freshets. This method of construction, simple and effectual as it may appear at first sight, is however, open to many and grave objections. If applied to rivers in the boulder stage, or in the sandy stage with high slopes, the embankments, usually very long, will be liable to breaches just before the rains, when storms are frequent near the hills, and the irrigation supply of peculiar value lower down the *doab*. The embankments may be maintained through minor floods, if great care is given to regulation by the temporary escapes, but they are never really safe and always a source of anxiety to the Canal officials and distress to the irrigators. When the system is applied to streams in the clay bed stage, the temptation to construct a strong and massive embankment is irresistible, frequently with the consequence of its remaining intact during the rainy season, the floods passing off, partly over the country, and partly through the earthen escapes and water-courses, which, scoured out and enlarged by the passage of large bodies of water, have to be repeatedly abandoned and re-dug in different situations. This process destroys large areas of valuable land, and interrupts the natural drainage; indeed, on the sites of embankments of this nature which have been maintained for long periods, the river channel is usually quite obliterated and its original course unrecognisable. Then again swamps are formed: it is usually so easy to raise the supply above the embankment to the ground surface, that this is nearly always done, with the result of turning the river bed above into a reservoir, in which jungle, grass, and weeds thrive with luxuriance (*see Plate* XII).

The cost of permanent works in rivers near the hills with small dry season supplies, broad beds, and heavy floods, may preclude their construction. In such cases the temporary embankment may be accepted as the only feasible system of utilizing the supply available, and the advent of the rains must then be considered the limit of the irrigation season for the year, unless a side channel exists suitable for special works, or a portion of the flood supply can be forced into the canal by a groyne or spur.

With the latter class of embankment, viz, those in streams having narrow firm beds, the scientific Canal Engineer should have nothing to do, except as far as lies in his power to arrange for their abolition and the *substitution for them* of properly designed masonry works, which will generally prove simple and inexpensive As a matter of fact in Northern India, these embankments, where they exist, are the survivals of Indian rule and local arrangements for irrigation The demands of sanitary science would long ago have caused their removal, had it not been for landed and revenue interests partially permanized by land settlement operations, carried out at a time when questions of drainage were less understood than they are at present.

It will be seen that the main distinction between a simple embankment and the most perfect system of temporary head-works, consists in the provision of a side channel containing a manageable proportion of *the river supply with its subsidiary works* *An estimate for a canal with* temporary head works will have to provide not only for the original clearance and regulation of this supply channel with its dams and escapes, but also capital sufficient to provide for the annual cost of the construc tion *of the temporary bunds*

22. Temporary bunds.—Temporary bunds may be built either of simple boulders, or of cribs or gabions and boulders If boulders alone or gabions are used, no special precautions are necessary to provide for the bund being completely washed away in the rains by the floods, but with cribs this is very necessary, as any obstructions remaining in the main river channel would tend to form islands by collecting floating *debris*, etc.

The cribs used at Hardwar for the Upper Ganges Canal are made up *(see Fig. 72, Plate* XI*)* of rough jungle timber nailed together on the river bank When it is desired to lay them in position, they are lifted *and carried by a derrick* fixed on a large boat, and when at the proper site, slowly lowered on to the river bed, being at the same time steadily loaded down with just sufficient boulders to prevent the crib being moved by the current as the work progresses Successive cribs being placed in position, the *quantity of boulders originally* placed is gradually added to, so as to provide against the increased velocity due to the heading of the supply, but great care is taken not to place more boulders than absolutely necessary to retain the cribs in position, the object being to avoid as much as possible the heading up *of the supply* until all the cribs have been placed.

Neglect of this precaution would cause scouring of the bed, and possibly prevent the successful completion of the bund. When the first operation is completed, all river water, except that going down the supply channel, will be passing through the cribs.

Cribs of this pattern can be manipulated up to 25 feet in height and successfully laid in 20 feet of water, or even a little more, if a double row is used; but depths beyond 12 to 15 feet are objectionable, and where the river shows signs of setting up deep local scour, boxed masonry bars should be put in to counteract this tendency. It is not necessary to carry the crib bar over shallows where plain boulders or gabions will stand.

When all the cribs have been laid, the bund can be slowly raised by the deposit of layers of boulders in the cribs, care being taken to keep the same level throughout. When completed the top level should be at least 4 feet above cold weather supply level to provide for freshets; at this period of construction all the river water, except the leakage through the bund, will be passing down the supply channel.

It is presumed that the operations to give a supply to the canal are commenced as soon after the rains as the state of the river will permit of a rope being got across and work put in hand. When properly conducted therefore, the gradual fall in the canal supply which would have resulted from the usual reduction of supply in the river after the rains, will be neutralized by the steady construction of the bund; in the same way the further operations for closing of leakage should be carried out as the level in the river gradually falls to the cold weather minimum.

The leakage is stopped by filling the interstices between the boulders in the bund with shingle and sand, and by constructing supplementary bunds below the main one which force the supply through secondary cuts into the supply channel below.

To stop leakage in the main bund a quantity of loose shingle is first thrown in front of the bund: this is partly drawn in between the boulders, but the balance forms an even bed for a mat (*Fig.* 73, *Plate* XI) roughly woven of coarse grass, which is placed in front of the bund, care being taken that its lower edge lies well forward on the natural bed of the river. This mat will be forced tightly on to the face of the bund by water pressure, and can then be well loaded down with sand and shingle; a large proportion of the leakage can be stopped off by this process.

The supplementary bunds are constructed in a similar manner to the main bund, but usually cribs are not required.

All Indian rivers worthy of supplying great canals, or suitable for bunds where cribs are likely to be required, are fed from the snows, were they not, they would fail in famine years

This source is the more valuable, because as the heat increases the snow melts faster and the supply of water in the river is thus increased in proportion to the demand

The increase to cold weather minimum supply from the rapid melting of the snows generally commences about the 15th April, and is always noticeable by the marked discoloration of the water. The increase in supply though gradual is not constant, a diurnal rise and fall occurs due to the different rates of melting during the hot and cold hours. Each rise, however, leaves an increment until the maximum snow supply is attained or the rains break This steady increase is of course interrupted by local rainfall or cloudy weather in the hills

As soon as the snow water comes down the river a partial dismantling of the bund is put in hand, the back battens are removed as far as possible, the ties of cribs lashed together cut, and the boulders in the strongest lengths partly removed, to allow of excess supplies passing over without causing serious injury to the general structure, the object being to maintain the bund in a repairable condition as long as possible to provide for contingent fluctuations in supply and demand When the operations are successfully conducted, the bund will not have entirely disappeared until a fair excess over full requirements is passing down the supply channel, with the head due to the natural river surface level

In describing the construction of temporary bunds, the main points only have been noticed the operations require considerable skill when carried out in rivers with large supplies and high velocities, the difficulties usually met with may often be reduced by the provision of permanent wire cables stretched cross the river abutment groynes and by other subsidiary works.

23 **Revetments**—A general widening out of the river bed will commonly follow the annual construction of bunds at the same site, this tendency is best counteracted by the provision of permanent revetments, which can be added to, extended, or improved from time to time as occasion demands. As a general rule, solid masonry walls of the style and type usual for works in the trough beds of rivers or the excavated canal channel, will not be found suited to the boulder bed or extreme velocities, for the form of work best calculated to defend the bank in such

situations would be only practicable in solid masonry with a vast expenditure of expensive material, and the buildings are so liable to total or partial destruction from the enormous forces acting in exceptional floods, that it would not be judicious to invest large sums in works, the duties of which can be well carried out by cheaper and simpler, if perhaps not so permanent and handsome, structures. Experience has shown that the best type of revetment is a well made crib work filled with hard material, left for two or three years open to the deposit of gravel or silt in the interstices of the filling, and then faced with a layer of masonry. This system has the advantage of spreading the expenditure over a series of years; no slight gain in the case of a reproductive work, and allowing of additions and extensions or alterations if experience shows any of these necessary.

Fig. 74, *Plate* XIII shows a common form of revetment, the crib boxes on the level of the river bed, forming the toe or apron, being firmly tied to the sloping cribs by long poles nailed or bolted to all the uprights. The woodwork for these revetments should be of the best round timber procurable, the joints, where not nailed, or bolted, being taper tenons well wedged with hard wood.

The position of the future masonry facing is also shown: before this is placed the top lagging should be removed, and consequently it will be found economical to construct this portion of the work of inferior timber, as it will only be required to last two or three years.

The whole structure is intended to be filled with well packed, and for choice split boulders.

The terminals of these revetments should be carried well into the natural river bank, and can, with advantage, be further protected with short broad groynes of similar construction, sloping at from 1 in 5 to 1 in 20 down to the level of the river bed and protected with aprons; when the revetment is very long a series of such groynes will be found advantageous spaced at intervals along the face.

As a general rule the head of the supply channel will require no regulating works except revetments, which maintain the width only of the channel constant without affecting the depth. Two of these revetments will run to a point at the river side of the head of the supply channel; and this point technically known as a redan, will require a specially strong system of construction, as it is exposed to the full force of the floods.

The necessary strength of structure is gained by presenting as sloping a face as possible in all directions to the current the crib work being triangulated as far as possible, well bolted together, and provided with a broad toe or apron of crib boxes The extreme point of the redan should be formed of a specially heavy log of timber well braced, the lower end being buried in crib boxes filled with masonry Timber is the best material for such a situation, as from its elasticity it is able to resist blows from trees floating down the river, which would disintegrate any ordinary masonry structure A sketch showing an ordinary arrangement of the upper river bund and revetments in the main river channel is given in (*Fig* 75, *Plate* XIII)

24. Cuts —The supply, dam, and escape channels, are the only cuts which can be properly classed under head works, excluding training works which are treated of under a separate section

The gradient of the main supply channel should be equal to, or slightly greater than, that of the main river down to the junction of the lowest supplementary channel below that point the slope of bed should be gradually reduced, so as to admit of a favourable entrance for the canal channel, and also to gain sufficient head to allow of the escape and regulating dams having a free fall into the main river, even when the latter is in full flood

It will be rarely necessary to entirely excavate the main supply channel. indeed the selection of the head work's site can hardly be considered satisfactory unless it includes an improveable existing channel, not only on account of the great expense of the excavation of a new channel but because it will always be found difficult to force the river to take in the manner required to a course, which it has shown no natural tendency to follow.

The line eventually selected need not, however, follow the course of a single spill throughout, if short cuts and connections can utilize two or more channels, converting them into one continuous line, the connections with the river thus cut off will form suitable sites for waste weirs or dams

When no natural spill can be found the best course is to make use of part of the main river bed, dividing it off from that portion of the channel reserved for floods by a permanent crib and boulder bund protected with spurs and warping up the lower portion of the supply channel with stepped crib bars

In this case to secure room for sufficient flank defence of the regulating dam at the canal end, the main longitudinal dividing bund should terminate on a natural island opposite the canal head.

It will nearly always be found necessary to warp up the lower portion of the supply channel with bars: but if this process is commenced before the other canal works have been far advanced, the expense will not be heavy, as comparatively few bars will raise the bed enough to place the dam out of danger, as a few years can be allowed for the deposits to accumulate.

25. **Canal Head and Under-sluices for temporary Head Works.**—The general arrangements of the canal head and under-sluices for temporary head-works will be similar to those required for permanent weirs, but in design they should be massive enough to withstand the heavy action they will be subjected to in boulder bed rivers. These works are always placed at the point where the supply channel rejoins the main river and the canal enters the permanent excavated channel. The design of the canal head requires special attention in three particulars, *viz.*, it should be situated so that the floods in sweeping past will not eddy, or form a backwater depositing shingle in front; it should be capable of being entirely and strongly closed against the entry of water in the highest possible flood, and the gates should be arranged so as to take off surface water only when small supplies are required in the canal during flood time. The *under-sluices* must be capable of disposing of all the flood water that can reach the point where they are situated, and as the heads of the cuts, from the main river which feed the supply channel are open and unobstructed, the quantity passed down during the floods may be considerable. *If the heads of these open cuts are properly revetted and their dimensions suitably calculated*, the amount of flood water passed into the supply channel will be fairly under control, the bed of this channel will retain its proper regimen, and the sluices will not be over-loaded. This necessary condition can be still further ensured by the interposition of one or more escape or relieving dams in the supply channel between the feeding cuts and the under-sluices.

26. **Escape Dams.**—*An intermediate escape dam from the supply channel* is a work intended to act as a safety valve to relieve the strain on the under-sluices in flood time. Escape dams may be of any suitable design, and should be situated in the bank of the supply channel next the main river, with a natural or excavated branch leading back to it. As a general rule it may be accepted that regulating arrangements at these

dams are objectionable because these require the up keep of a permanent establishment at an isolated point and the power of regulation once given is liable to be misused, turning the escape dam into a secondary under sluice which not being properly situated for such a purpose causes shingle deposits to form in the bed of the supply channel and a general disturb ance of the proper regimen of the head work installation It is there fore preferable to construct an escape dam as a simple cill or crest wall built to a level sufficient to take off flood water passing down the supply channel in excess of the power of the under-sluices there will be no particular difficulty in arranging this if the entrances of the temporary bund feeding channels are properly revetted and the under sluices power fully built

MAIN CANAL WORKS

27 **Scouring Sluices** —A scouring sluice is a work intended to free the upper reach of a canal from the deposits brought into it from the river Deposits are more liable to form just below the head or entrance to a channel than in any other portion because of the change of velocity and direction and the scouring sluice is intended to give a power of increasing the velocity in the upper reach so as to erode these deposits after they have occurred or to prevent their formation The utility of this device is however, questionable when the silt has been deposited and the sluices are used to remove it the increased velocity will be found to have very little useful effect unless very heavy supplies are forced down because even rapid *currents erode their beds slowly and with difficulty The* most cursory observation of the action of a river changing its course will show that the soil cutting action occurs at the sides and that when the current is forced *to erode* the bed the action is generally local and accom panied with much surface disturbance of the water Again if the sluices *are used to increase the velocity of the upper reach and prevent depos*its when a silt laden supply is entering the canal it is evident that although a useful effect will be produced in the reach above the sluices the velocity below them will be suddenly reduced and the deposit form there.

When scouring sluices are considered necessary they can be ...

curved and gentle entry *for the river water and to* ... g ilating gates arranged to take off *surface water* ... *silt laden* This care in most cases will avoid ...

scouring sluices, works which in any case can well be postponed until an urgent necessity for their construction is felt.

Mr. J. T. Farrant, who has had great experience with silt operations in the Punjab, states in his Report (Punjab Irrigation Branch Paper, No. 9)—'the conclusions to be drawn then are that only very light, probably micaceous sand is held in suspension and carried forward by the water, that all the coarser sand travels along the bottom; that the silting of the canal is almost entirely due to sand rolled into the canal from the river bed * * * "

28. **Torrent superpassage works.**—Between the point at which the line of the canal channel leaves the river and reaches the main watershed of the country, it nearly always happens that drainage has to be crossed, and whatever the quantity of discharge may be, it is necessary to provide for its disposal, so that neither the canal itself nor the adjoining country may be injured. When the drainage lines crossed are important streams close to their debouch from the hills, the structures required to dispose of the floods are called *torrent works;* when the drainage interfered with by the canal is comparatively small in quantity, moving with low velocities, or when it is a case of drainage lines requiring adjustment by reason of the construction of irrigation works, the operations required are termed *drainage works.*

There are several methods of adjusting torrents so as not to interfere with the canal. The most general works employed are *Diversion, Superpassages, Level Crossings. Aqueducts, Inlets and Outlets, Reservoirs* and *Training Works,* which last class of work may be considered a concomitant of all the others, being generally required to maintain them in the condition in which they have been constructed.

29. **Diversions.**—Drainage is diverted by altering its course so as to make it run clear of the canal: this expedient is often economical, but can only be thoroughly successful in special cases, because the diversion must cross a watershed and pass through elevated land; the cut will, therefore, have to be very wide to be fit to cope with exceptional floods. It may be taken as an "axiom" in all drainage operations, that the proper course for a drainage line is along the true drainage depression, and that short cuts through watersheds, however convenient they may appear at first sight, will almost certainly lead to inefficient working in the future. For torrent adjustment, however, a diversion may at times prove a necessary expedient in view of the prohibitive expense of other means of

constructing a large work. An instructive example is afforded by the diversion of the Chakki torrent on the Bari Doab Canal, for the passage of which costly works were originally designed. The Chakki, when the canal works were commenced had two outlets, just above the crossing point of the canal the main channel divided—one the large branch, running into the Beas, the other into the Ravi The latter branch was embanked across at the bifurcation by boulder dams and spurs of the same material, protected at the extremities by masonry revetments By this means the whole of the water was forced to flow into the Beas and the expense of the works for a canal crossing saved.

In cases like the Chakki diversion is perfectly legitimate provided the channel into which the whole supply is diverted is not liable to cause extensive injury to the country by flooding until such time as its capacity has been enlarged by scour to the increase in volume of flood water it will have to carry, such simple cases will rarely be met with in practice.

30. **Superpassages**—The gradient of a canal channel situated near the hills will, as a rule be less than the general slope of the country. It follows from this that the canal bed will at first be below the general level of the country, and the shallow torrents then attain the same level, and finally pass on to the watershed elevated above the beds of the hill streams. This alteration of position is the more quickly arrived at because the torrents, as they get further from the hills, change from the elevated *fan* stage to channels slightly depressed below the country

These conditions involve three distinct classes of works for carrying torrent floods across the canal—the superpassage which carries the flood over the canal, the level crossing which takes it through but at the same level, and the aqueduct, which carries the canal water over the torrent.

Superpassages have the advantages of keeping the canal channel free from any influx of torrent flood water, of not requiring the maintenance of large establishments, of allowing the canal supply to be kept up uninterruptedly during floods, and of being useful as bridges of communication These works are also generally inexpensive to maintain

The disadvantages of superpassages are the expense and difficulty of construction, and the necessity that exists for training works (to direct the torrent on to the superpassage) which always require careful watching *A large water channel has to be provided to carry extraordinary* floods over the canal in safety, and sufficient headway must be allowed under the superpassage so as not to interrupt navigation For this

purpose it is often expedient to build a fall in the canal, combined with, but situated above, the superpassage; this will help to give the headway required, a lock being provided for navigation purposes.

Apart from the special difficulties of construction, selection of suitable point of crossing of the torrent, and level of floor, a superpassage is a simple work to design, as it is merely a bridge with parapets high enough to contain the floods. The peculiarities of the flow of water on torrent beds have been mentioned previously, and will require careful consideration when a work of this nature is being designed. The construction should be massive and of the best material, the wings being carried well into the canal banks to avoid any danger of the torrent breaking round them into the canal. The foundation should, if possible, be a mass of concrete laid within a coffer-dam; but as these works are of necessity built at a great depth below the bed of a torrent, considerable difficulty from springs must be anticipated during construction, and the proper foundation to select can only be determined on the results of careful borings into the subsoil. There are no substantial objections to founding a superpassage on well blocks if good concrete cannot be put in. If a canal fall is combined with a superpassage, a protected puddle apron above the fall on the bed and sides of the canal will be necessary to obviate creep.

Properly designed training works should be considered an essential part of a superpassage, and indeed of every torrent work. The whole surface of the area draining across the canal must be demarcated, levelled, and examined with great care before any of the works are finally decided on, and the map thus prepared, should form the basis for the design of a complete series of training works, consisting of groynes, spurs, cuts, etc., arranged so as to maintain the proper direction and depth of channel of the torrents and streams as they approach the canal works.

31. **Level Crossings.**—A level crossing is a work constructed so as to pass the flood water of a torrent or river through the canal on the canal bed level. The nature of this class of work will be easily understood from (*Fig.* 76, *Plate* XIII). B is a regulating bridge across the canal channel provided with the usual gates. A is a dam across the channel of the torrent provided with flood gates. Under ordinary circumstances A is closed and B is open, so that the canal water flows along as usual, flooding however up the torrent channels as far as the bed slope allows. When the torrent is in flood then A must be open and B closed, so that the flood water may cross the canal and flow down its own channel.

The advantages of a level crossing are that there is little danger of injurious deposits of torrent silt in the canal bed, that the dam acts as an efficient regulating escape for the canal, that extraordinary floods may be passed off with a very slight afflux, and comparative economy of construction, for the only other means of passing a torrent flood across the canal would be syphon it, and syphons are both expensive and unsuitable works for the conveyance of very large quantities of silt laden water When trees or other floating *débris* are likely to come down with the flood, a syphon would be out of the question.

When the canal is running the level crossing will block the natural drainage of the country on the torrent up-stream side of the canal to the extent of the depth of water in the canal If the drainage thus blocked is likely to damage the country, it will be necessary to provide tunnels or syphons to pass it under the canal, but these passages should be carefully protected from any influx of the torrent floods which would be certain to wreck them Another disadvantage of a level crossing is that it entails the necessity of keeping a permanent establishment of men on the spot to work it.

The general details of construction of the regulator and dam comprising a level crossing will be similar to those required for other works of this nature, but the following special precautions will be necessary The canal channel for some distance above the crossing will require revetting on the banks and protection to the bed from scour, because when the dam is opened with the canal full, the canal supply will continue to pass through the dam along with the torrent flood until the canal head is closed, and a high velocity of approach will be set up near the dam. The gates of the regulator should be hung so that they can be dropped without any delay, completely closing off the canal below from flood water, which if admitted, would silt up the channel very rapidly These gates ought to be of the regulating pattern so as to restore the supply to the canal from surface water as soon as the flood begins to subside. The canal bed at the crossing and above and below the regulator, requires a liberal supply of protective pitching laid over a retentive puddle platform, if this can be laid with reasonable economy

Below the dam the river bed requires special protection from scour, and if the bed slope of the torrent is high a steady retrogression of bed level may be anticipated with certainty, and should be met as it occurs by the construction of a series of strong crib bars loaded with boulders or other heavy material These bars in process of time can be made permanent structures by replacing the timber with masonry work.

The gates of the dam must be arranged with catches so that they can be dropped open at a moment's notice. Floods in torrents with high bed slopes often come down with great rapidity from sudden flushes of rain on the gathering ground, and as the passage of the flood is entirely blocked by the dam, even a few minutes delay might lead at times to serious damage to the works.

The finest example of a level crossing as yet built in India is at Dhanauri, on the Ganges Canal, where the Ratmū torrent is passed. A sketch of the arrangement of these works is given in (*Fig.* 77, *Plate* XIII). A plan of the drop gates used on the Dhanauri Dam is given in *Plate* XIV. These gates are simple to build and fit in place, and have acted well for a number of years.

32. **Aqueducts.**—An aqueduct properly speaking is a channel for conveying water either above or below ground, but on canals the term aqueduct is generally confined to the structure actually spanning a river or other waterway and carrying the canal over it. When combined with a long earthen elevated channel, it is called the aqueduct proper to distinguish it from the embankment—all these distinctions being of course a mere matter of convenience. An aqueduct only differs from a bridge in having to carry a water channel over it instead of a railway or road: the bridge part may be made of wood, iron, or masonry, but for works of any magnitude, masonry will be found the most economical, lasting and effective material.

The valley drained by the torrent or river over which the canal has to be carried will be embanked across in the usual way, care being taken that sufficient waterway is provided under the aqueduct for the maximum flood.

Many engineering works can, with propriety, be designed to carry only ordinary maximum floods* on the ground that it will be more economical to repair the damages of an extraordinary flood which, though possible in theory, may never occur, than to invest large sums in the construction of works larger than required for ordinary use. It is not safe to apply this procedure to aqueducts or to the major torrent works of large canals, even though it may be financially sound as far as the cost of construction is concerned, because these works must necessarily take a long time to repair or renew, and the want of them will cause a cessation of that unfailing supply of irrigation water which, on the opening of a canal, becomes a necessary concomitant of prosperity to the tract commanded by the canal.

* For discharges of drainage basins *see* para. 54.

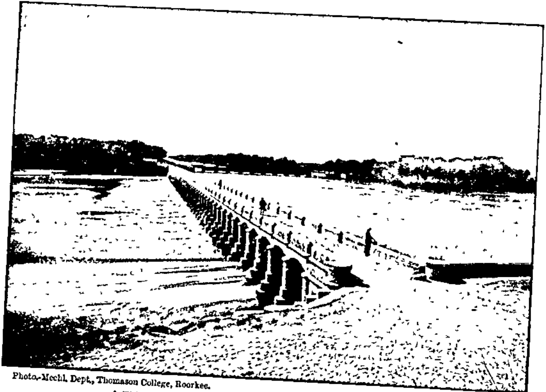

Photo.-Mechl. Dept., Thomason College, Roorkee.

LEVEL CROSSING, DHANAURI, GANGES CANAL.

The following details of construction of aqueducts require special attention

The alignment for the river crossing should be carefully selected so as to give the minimum length of embankment compatible with a straight and permanent reach of river at right angles with the direction of the canal line It is permissible to found the aqueduct proper on a site apart from the existing river channel if it can be determined that a straight cut, combined with proper training works, will eventually bring the river properly under the aqueduct and keep it there Indeed, there are many advantages in following this course, as it allows of the works being carried on without suffering inconvenience from moderate floods, etc.

When there is a long embankment over the valley, special care should be taken to design the aqueduct training works so as to avoid any chance of fluvial action near the embankment

With regard to the main structure of the aqueduct proper, the prevention of unequal settlement must be regarded as of the first importance In this light an arched structure supported on inverts resting on a mass of concrete would appear the best form to adopt, and so it will be for rivers with a confirmed bed, but this type of design would be unsuitable for torrents in which the true bed during floods is often far below the level at which the sand remains when the flood is over In the latter case deep well block foundations under the piers are most suitable Before building the piers on them, it will be necessary to test the power of these blocks to support the load they will be called upon to carry when the aqueduct is completed and full of water

When a permanent floor of any kind on the river bed is a portion of the design, it must be protected by pitching of heavy material up and down stream

The provision of sufficient pitching up stream of bridges and aqueducts is sometimes overlooked, but experience shows that this precaution is very necessary, indeed the slow and apparently gentle swirl of water above a contracted waterway has often greater erosive power than the more noticeable action below it.

When no floor is provided the surface of the river bed should be faced with loose heavy material under the arching and for some distance above and below. This material should be placed as far below the bed level as it can be got in conveniently, it is required to prevent unequal scouring out of any particular bay or bays of the waterway

The canal water wings of the aqueduct should be designed long enough to make a thoroughly strong joint with the embankment. This will entail considerable expense, as it is evident that unequal level of foundation is not permissible in aqueduct design, as this would inevitably lead to unequal settlement. It is also necessary to equally proportion the supporting power of the foundations of the parts of the structure to the weights they will have to carry, so that whatever settlement does occur may be uniform for the whole building.

The weight of an aqueduct loaded with water must be considerable in any case, and every means of reducing the pressure on the foundations should be considered: thus, when the flood headway is ample, it may be found judicious to adopt arches of a considerable rise with hollow spandrels, the floor being carried on minor spandrel arches.

The canal channel of the aqueduct must be made water-tight: this, even when the leakage is insignificant, is not merely a matter of appearance but of necessity, because the water slowly percolating through the floor dissolves and carries away the lime of the mortar with it and weakens the structure. A layer of well-puddled clay covered with the very best fine concrete will be found an efficient protection against leakage: the dimensions necessary will depend on the head of water, but one foot of puddle and six inches of concrete will be sufficient for ten feet of water if the best material and workmanship is used.

If a suitable entrance and exit is designed, the canal masonry channel of an aqueduct may be built of less width than the earthen channel; when economy is of great importance the width may be considerably reduced without causing much afflux.

Roadways are necessary on both sides of an aqueduct to ensure proper inspection and repair of such important works.

The embankments of an aqueduct will require puddle walls, unless the earth available for their construction is of very good quality; the bed should be carefully protected from erosion by bars of hard material if the velocity of the supply is high. The greatest care is necessary for the earthwork of heavy embankments and it will be found judicious to carry it from all the flanks, and to avoid the minor economy due to borrow pits near the embankment itself. Water should be used freely for consolidation, and the retentive capacity of the channel tested frequently as the banks are being raised.

The Solani Aqueduct near Roorkee on the Ganges Canal, and the Nadrai Aqueduct on the Lower Ganges Canal, are fine examples of this class of work in the United Provinces, India.

33 **Inlets and Outlets**—Drainage water intercepted by the canal line may be allowed to pass into the canal if the quantity of water is too small to warrant the expenditure necessary for a permanent work suitable to carry it across the canal if it does not bring in an injurious amount *of silt and if the water* passed in can be again passed out of the canal by a special outlet or an existing escape without the drainage water interfering with the proper regulation of the canal supply. Inlets should be designed to be self regulating so as not to require the up keep of establishment they should be strongly built of masonry, either as tunnels through the canal bank with cills at the level of the bed of the drainage, or as waste weirs. When near villages the discharge over the cill may be made thin by widening it and the floor of the waste weir be stepped down so as to form a bathing *ghât* The masonry work of inlets should be protected with pitching It will be seen from the foregoing that inlets cannot conveniently be built except when the drainage bed is above canal full supply; if below it the canal water will be liable to flood the country causing swamps Outlets are required in connection with inlets when there is no escape lower down the canal suitable for removing the inlet drainage water As outlets must necessarily be regulating works they are objectionable if isolated, on account of the expense of establishment The design of outlets for drainage may be similar to that of ordinary escape dams

34 **Reservoirs**—The canal channel may intercept drainage difficult of adjustment by any of the works just described, thus a number of minor *discharges may be met with individually too small to warrant the con*struction of separate crossing works, yet impossible to divert either away from the canal or into one common crossing The level of a drainage carrying silt may be too high for a level crossing yet not high enough for a superpassage, and it will evidently be bad engineering to pass it in to the canal by an inlet, or under it by a syphon on account of the anticipated deposits In such cases if the general contour and condition of the country above the canal line allows of the procedure, a reservoir may be arranged for, and the accumulated drainage passed over the canal by a superpassage during the flood time, the reservoir itself being afterwards freed from water by a regulating culvert or syphon under the canal

If the conditions are favourable there are many advantages in this system of dealing with floods, particularly when the surface of the reservoir is land of bad quality, because this will be improved and rendered [illegible]

of high cultivation during the dry season by the flood deposits over its surface. The engineering advantages are the regulation of the flood discharge caused by the reservoir, and the removal of the silt by slow deposit allowing of a clear water discharge through the low level outlet.

An interesting example of this class of work is given by the Ali Reservoir, five miles below the head of the Agra Canal, United Provinces. Here a large stretch of low ground was intercepted between the canal bank and the high table-land down which the Ali and Madanpur torrents carry off to the Jumna river the drainage of the rocky hills on the right bank of the canal. The floods rise rapidly but are of short duration. The flood water first collects in the reservoir, and when it rises high enough, the excess flows over the Ali superpassage which consists of an iron trough 30 feet wide and 10 feet deep, with a discharging capacity of 2,000 cusecs. The reservoirs cover 500 acres, and have a storage capacity of 160,000,000 cubic feet. When the silt has subsided in the reservoir, the valves in a water-tower are gradually opened, and the water below the floor of the reservoir is passed under the canal to the Jumna. The reservoir bed is very fertile owing to the deposits, and rich crops are grown upon it.

35. **Regulation Works.**--It is evident that the surface level of the canal must fluctuate with the supply in the river and the demand for irrigation, and that works are required to regulate it. Some of these works can be arranged to work automatically, others will require constant and careful management. Works constructed to obviate an excess slope in the country over that required for the bed are also included in regulating works.

Canals carrying a considerable supply of water and feeding distributary channels, will necessarily require the constant interference of regulating establishment, but the ideal distributary should automatically control its supply once the head sluice has been opened and adjusted.

The following include the ordinary types of Regulating works:—

Regulators, Falls, Rapids, Bars, Escapes, Gauges, Discharge Sites, Telegraphs.

36. **Regulators**.—The special points requiring attention in the design of the canal head regulator are given in paragraph 17, and these remarks are applicable to all regulators working under heavy heads of water and to branch heads, though of course in a degree modified by the strains to which the works will be exposed. Regulating gates taking off surface

water only are necessary for branch heads to avoid silting the upper reaches For the same reason when it is possible to do so, the branch should leave the main canal at an acute angle with a skew head.

In paragraph 16 Chapter V, the necessity for providing remedies to the inevitable alterations in depth and scouring power of the canal supply is pointed out Regulators for this purpose are simple structures, consisting of a floor supported on a concrete foundation with a piers grooved *to hold the planks required for temporarily raising the water surface* level—a moderate amount of pitching is required above and below the works Puddle aprons should not be necessary because regulators of this class should not be required to raise the surface level more than one to two feet at the most If the canal is navigable a boat bay will be required The piers can be spaced 6 to 8 feet apart and communication for the regulating establishment provided using planks laid from pier to pier or by arching the piers which is the best plan, as it braces the whole structure

It is not necessary to keep up a special regulating establishment for a regulator of this class the placing and removal of planks should be the duty of the men employed at any large work in the neigbourhood

37. Falls—The works by which the bed is led down from a higher to a lower level are called Falls and their design and construction are questions requiring much thought and experience The location must evidently be near the place where the canal bed, if continued without a step down, would have to be carried in embankment above the surface of the country The exact site will be determined by local considerations of which the chief is the nature of the soil for the foundation but in any case it is expedient to keep the work itself well in digging, as a fall built in embankment would always be a source of anxiety

The forces developed by the fall of a large body of water down even 6 or 8 feet are very considerable, and require not only a strong, but a specially designed work to withstand their effects The necessity for special precautions will be at once apparent if we consider the results of allowing a body of water uncontrolled to pass over a plain fall (*see Fig* 78 *Plate* XIII)

The necessity of conteracting the draw over the fall at A led first to the introduction of temporary planks to raise the cills and restore the water surface to the normal but as the placing and removal of these planks in broad bays with a heavy rush of water over them was found difficult and dangerous, masonry cills were built permanently raising the crests At

same time the depth of *water cushion at B was increased* either by
ding a wall below the fall on the floor to form a raised cistern, or by
ing a deep cistern below the level of the floor.

The same results were attained by fixing a heavy waved grating at A
ined over B, the water headed upon the grating passes through the
restices with reduced velocity, as it were through the teeth of a comb
Fig. 79, *Plate* XIII).

Briefly the objections to these remedies are as follows :—The raised
A is non-regulating, and therefore only acts perfectly with the special
th of water in the canal for which it was calculated; this difficulty has
ı overcome by the introduction of the *notched raised cill,* vide para.
Chapter V.

The cistern wall B answers its purpose well; it however, causes a
nd minor fall of water below itself, but this only necessitates an addi-
to the flooring. The sunk cistern *C* is also efficient as a remedy to the
k on the floor, but it has little effect in preventing the great reduction
ırface level of water immediately below the fall, *see* B, *Fig.* 79.
cistern is also expensive to construct necessitating deep and unequal
dations of the fall, which is objectionable.

The grating D is efficient but expensive to construct and maintain, as
liable to get choked with floating *débris.* On the whole a vertical
with a notch raised crest and a low cross wall below a slightly sunk
rn appears the best design for a fall.

ın increased velocity of departure from a fall must, under any cir-
tances, be expected, and as this means a reduction in depth of water
is point, it is necessary to keep the long lower water wings and
ed revetments below the fall parallel to the centre line of the canal,
the surface attains its normal level. This will to a great extent,
ent eddies, swirls and cross currents, all of which are increased if
be given to the water to return in the direction of the fall to fill up
epression, by widening out the wings below the fall—*see* also Machua
, para. 14.

he pitching below the fall floor should be of the best quality, but
outed; wood cribs and sheet piling are suitable to compact the
ing where the action is most severe. A strong loose stone bar 150 to
eet below large falls will generally be required as an additional
ction.

protected puddle apron above, carefully jointed in with the masonry
cill, is an essential part of high falls, as these works are especially
sed to danger from creep.

Photo.-Mechl Dept Thomason Co lege Roorkee

BAHADURABAD FALLS GANGES CANAL

Falls, when large, are usually divided into bays of 20 feet wide or less The bay wall can be utilized as a pier for the arches if a bridge is combined with the fall, and should be continued the whole length of the floor to aid in the repair of an injury by isolating it. The best foundation for a fall is a mass of concrete underlying the best of brickwork, the floor must be faced with large heavy blocks of stone of good quality, if it has to stand the impact of the falling water from a considerable height.

38 Rapids.—Instead of falls, rapids have been employed to accomplish the necessary change of level The drop is laid out on a long slope about 1 in 15 The slope is paved with boulders laid dry, or with mortar confined by masonry walls at intervals of about 40 feet both longitudinally and across stream The sides and flanks also require protection and a talus at the foot of the rapid on the level bed of the canal is of course a necessity The best form of rapid is that in which the slope is reduced as it descends so as to gradually assimilate with the bed of the canal at the tail

It has been found by experience that brickwork will not stand velocities of 10 feet per second and that at 1 in 15 rapids of boulder work will not stand 18 feet per second Boulders or rough stones are, within these limits, the most suitable materials for rapids, and as it is desirable to offer as much resistance as possible to the descending water, there should be no attempt made to bring the surface of the work up smooth, the stones should only be packed on end with the tops fairly level (*see Fig* 80, *Plate* XIII)

39 Bars —A succession of crib work bars placed across the canal at close intervals is occasionally used to correct the results of too high a bed slope. The crib boxes are filled with heavy material *and the flanks well protected* Even when the total correction of slope *for a long* distance over these bars is slight the action will be severe at first and erosion of the bed and flanks is likely to occur In time the bed between the bars will rise from deposits and the action be confined to a slight fall of water over the bars

When the bed of a channel has been deeply eroded for a long distance these bars are no doubt a suitable means of correcting the evil but they need careful attention for many years until they have produced the desired effect, and in some cases they may be more expensive in construction and repair than an interpolated masonry fall but they have the advantage of not requiring the up keep of establishment for navigation

40. Escapes.—Escapes are required in order to establish a complete control over the supply in the canal. An escape consists of a regulating head and a channel connecting the head with a natural drainage line. In order to have the power of forcing the whole supply down the escape a regulator across the canal is sometimes included. The escape head is similar in construction to an ordinary branch head, but a fall below may be included with advantage, as it causes a better draw down the escape. The channel, if artificial, will of course be designed to carry the calculated supply. If the channel is a selected natural drainage line it will need very careful examination to ensure that *all along its course* it is capable of carrying the required discharge without flooding or injury to land or crops. The same remarks apply to the channel into which an artificial escape channel ultimately tails, and it must be remembered that escapes are liable to be run during times of heavy rainfall when natural drainage channels are heavily charged with flood water.

An imperfect natural drainage line is often capable of such improvement as will render it suitable as an escape channel, and, broadly speaking it is generally better engineering to improve an existing natural line than to dig an artificial channel.

Escapes are also required at dangerous points of a canal, such as above a long embankment; in such cases they should be capable of disposing of the whole volume of the canal.

It requires care and attention to details to allot the escape power properly over a great length of canal line. The worst case occurs when the canal is running full supply with a strong demand for irrigation, and heavy rain falls suddenly over the whole tract causing floods, and the immediate cessation of all irrigation. This involves the closure of all distributary and branch heads unprovided with the means of disposing of their own supply, and an increase in the volume of the water in the canal from the rainfall itself, from inlets if any such exist, and possibly from breaches in the canal banks. Now it may be assumed that the canal supply will be cut off at the head from information received from below as soon as that information can reach the head (*see* para. 41), and that the canal channel can carry the volume calculated for each of its sections without injury to the works or the country.

The data thus obtained should be laid down graphically on a chart, and the escape power fitted in to correspond with both the demand for it, and the points at which it can be applied conveniently. Care must be taken to ensure that the canal channel itself is designed so as to be capable of

carrying to the escapes the volume the latter are supposed to discharge In calculating the escape power no credit should be taken for a reduction in volume due to the closing of the canal head, this closure should be looked on as more useful in reducing the time over which a flood will last than the volume.

All main canals, branches and distributaries ought to be provided with terminal escapes of sufficient capacity to dispose of the tail discharge at least, in some cases branches and large distributaries may be constructed with advantage so as to act as canal escapes to a moderate extent

Escape channels require as much care in designing as the irrigating channels, and should be provided with falls and all other necessary works The construction should be specially massive and enduring as these works do not as a rule, benefit from the frequent inspections which are essential for the channels from which irrigation is directly carried on

41 **Gauges, Discharge sites and Telegraph** —Gauges to record the variations in depth of the supply at selected localities are essential parts of the regulating apparatus of a canal A discharge site is generally associated with a guage in order that by frequent experiments the volumes corresponding to the readings of the guage may be accurately determined, and on large channels a telegraph line is carried from guage to guage to supply the means of communication for quick correction of errors in the volume of the supply passed down the canal

A guage ordinarily consists of a wood or metal rod divided into feet and tenths, the zero being the reduced level of the canal bed it is usually fixed in a still water chamber, vide para 19 Gauges are required at the heads and tails of all channels, in the main line at the heads of branches or escapes, and above and below all regulators for works where there is a marked change in the level of the canal supply.

A discharge site is a length (generally 150 to 200 feet) of correct cross section of the channel To confirm this, the length is usually lined by masonry walls, or dry brick or stone revetments, and a suitable protection to the bed The guage is fixed in the centre of the length at one or both sides The discharge site should be provided with standards and wires crossing the channel at the centre, and at 50 feet above and below the centre so as to give a clear run of 100 feet for float velocity observations, also with arrangements for observing the slope of the water surface over the 100 feet length The bed protection should be smooth and level transversely, so as to allow of mean velocity rods being run

close to the bottom. Discharge sites are required at the heads of all canals, branches and distributaries, and at any other point where it is necessary to pass on certain fixed proportions of the canal supply to authorities other than those directly controlling the discharge at the head.

Telegraph and telephone lines are a valuable, in some cases a necessary, addition to the regulating power of a large canal. The telegraph office should be situated at the sub-divisional headquarters if possible, so that the signaller may be usefully employed when not engaged on his regular duty. As the headquarters itself ought properly to be placed where a good command of the regulation is attainable, the telegraph office will thus be near important groups of gauges.

Canal telegraph lines correspond with those maintained on railways for clear line traffic, and should be open to the public on similar terms; they will also be found useful for rapid communication between the members of the canal establishment, simplifying and reducing the ordinary official correspondence.

42. **Communication works.**—The ordinary works for communication on canals are bridges and diversion roads. Bridges may be classified as *First class* for metalled roads, requiring at least 16 feet between the kerbs: *Second class* for unmetalled roads, requiring at least 12 feet; *Occupation*, with a width between kerbs of 10 feet.

Other ordinary classes of bridges on canals are those required for *Railway* and *Cattle* crossing, *Foot and Temporary bridges. Ghâts* and *Ferries* may also be considered works of communication. On navigable channels care must be taken to provide sufficient headway under the arches or openings of canal bridges for boats to pass easily when the canal has its full supply. On up-country canals in India, a rectangle 10 to 13 feet high and 20 feet wide above high water surface will usually be found sufficient. Owing to this condition and the general necessities of the case, the road-ways of canal bridges are often higher than the general level of the country, and care must be taken to provide proper approaches so as to hinder the traffic as little as possible; the gradient should never be less than 1 in 30, and 1 in 40 is necessary on metalled roads.

It will often be found judicious to adopt iron girders instead of arches to support the roadways of canal bridges, particularly when a clear headway is desirable.

It will be found economical in the end to metal the approaches to all classes of bridges, as it preserves the earthwork from injury; the wear

and tear of unprotected approaches is very heavy, particularly when cattle traffic is heavy A low earthen wall along the edges of high ramps will also be found efficacious in preserving them from injury.

The other special points of construction of the canal bridges are as follows —

Strong wide kerbs and heavy low parapets are preferable to unprotected high parapets, foot paths are rarely necessary. The drainage of long approaches should be provided for, and bumping stones fixed at the points where carts are liable to injure the masonry.

Deep foundations are unnecessary except for very bad soil. Concrete platforms under the piers with flat floors, or inverts in the case of heavy bridges of wide span will usually be found suitable The volume of supply being under regulation and the channel designed to suit the discharge, the action through a canal bridge should never be severe, but the floors of bridges are useful fixed points of level of the canal bed to indicate any alterations of level that may occur If floors are found too expensive, narrow masonry bars on the bed level up and down stream should be built, the intervening space being pitched An apron and curtain of heavy pitching should also be provided

On navigable channels, bridges should be provided with tow-paths under the arch on the side used for towing.

Water as well as land wings are almost a necessity for large bridges, and if bathing *ghats* are added when the work is situated near a town, the expense will be well repaid by the comfort it will afford the people, and the saving of damage to the earthwork near the town.

The general design should be adapted to the attainment of an equal foundation for the whole work If the foundations are laid at different levels, unsightly, not dangerous, cracks are certain to occur after the canal has run for some time.

Works of communication ought to be provided over a canal wherever the traffic is seriously interrupted by the channel Naturally the larger the channel the further apart the bridges must be owing to the great expense of large works A good deal of inconvenience may be avoided by the construction of diversion or accommodation roads, and by taking great care in the selection of sites.

On great canals, bridges should in no case be more than three miles apart and may well be closer. On small branches and distributaries the interval should not exceed one mile.

The borrow pits for the earthwork near bridges should be carefully laid out so that the adjoining land may neither be injured nor rendered unsightly.

43. **Navigation works.**—It is a moot point with Engineers in India whether Irrigation canals should be provided with facilities for navigation or not. The objections are the expense, both of construction of the works necessary, and of maintenance and establishment, the reduction of velocity of current to meet the requirements of navigation where the soil would stand a high velocity, and the practical impossibility of competing with railways in cost of transport.

If canals are looked on as purely commercial undertakings these objections must be held to have great weight, although the imperfect means of transport hitherto employed in Upper India is no doubt responsible for the high rates of carriage; but if canals are viewed as great Public Works it is manifestly improper to construct a magnificent waterway through a populous country, and leave it blocked for navigation for the want of a few minor works. In any case, however, navigation must be considered a subsidiary function of a work primarily constructed for irrigation, and the remarks in this section will be confined to the ordinary methods of providing the means for carrying small cargo boats round those works of the canal which would otherwise obstruct their passage.

The works which are obstructive to navigation on a canal are those where the level of the water surface is suddenly changed, such as Weirs, Falls and Regulators; as the obstruction by the latter class of work is likely to be temporary, special works to pass them are rarely necessary.

Boats can be passed round falls and weirs by means of locks, or vertical mechanical lifts or inclines. The lock can be built either as a part of the major work, or as a separate structure connected with the canal by navigation channels, *vide Fig.* 81, *Plate* XVI.

The advantages of combined works (*see* plan of Regulating Fall, *Plate* XV) are economy of construction and the direct route obtained for the traffic. The disadvantages are the danger of placing such a heavily strained work, as a lock must be from the frequent severe changes of hydrostatic pressure on its structure, close to large and important works, on the safety of which the maintenance of the irrigating supply depends.

Probably the best solution of the difficulty in the case of very large works is to build the lock as a separate structure, but close to the main work with the minimum length of navigation channel possible. A general

idea of the construction of locks, and the method of passing boats through them, will be obtained from *Fig.* 82, *Plate* XVI of one of the old type of locks built on the Ganges Canal.

Suppose that a boat has to pass from the upper level A to the lower B, the upper gates (*a*) being closed and the lock chamber empty The lower gates (*b*) are first closed and the sluices at the upper gates opened by which the lock chamber is filled with water, the upper gates are then opened and the boat passes into the lock chamber, when the upper gates are closed and the sluices in the lower gates opened to let out the water This lowers the boat to the level of B the lower reach of channel, and the boat can pass out when the lower gates are opened The process has of course to be reversed when the boat has to pass from the lower to the higher level

The dimensions of the lock chamber must depend on the sort of boats used and the amount of the traffic. In Northern Indian chambers 150′ × 20′ are now used

In *Fig* 82, *Plate* XVI a by wash is shown in combination with the lock chamber, this is useful for passing extra volumes of water down the navigation channels and affording facilities for the supply of water power to mills, etc, but it is better, on the whole, to omit all subsidiary works, and to make the structure of the lock as simple as possible, sluice power sufficient for all requirements being provided in the gates

Sluices fixed in tunnels in the lock walls, passing from above to below the gates are also permissible but require careful lining, and the sluice gates should be provided with friction rollers for high lifts

The upper and lower lock gates should be well balanced and carefully fitted to avoid difficulty in moving them and leakage of water when the lock is full. The more acute the angle of meeting of the gates the less will be the compressive strain on the structure of the gate in the direction of its width, but on the other hand wide gates are expensive and take up more room in the lock chamber. The usual practice is to make the rise of the mitre cill, when the gates abut at the floor, equal to about one fourth of the span,

In general it will be correct to design a lock with the side walls resting on an invert supported by a solid mass of concrete—puddle should be freely used both in an apron above the cill and behind the walls

Professor Rankine gives the following dimensions and proportions of *navigation channels* required to prevent any material increase of resistance to the motion of a boat beyond what it would encounter in open water —

Least breadth at bottom $= 2 \times$ greatest breadth of boat.
depth of water $= 1 \cdot 5' +$ greatest draught of boat.
area of water section $= 6 \times$ greatest midship section of boat to water line

Side slopes not less than 1 in 1·5.

It is however often advisable to revet the side slopes to ½ to 1.

A typical section of navigation channel is given in (*Fig.* 83, *Plate* XVI), showing tow-paths at A A.

44. Accommodation works.—The following works of accommodation are required on irrigation canals, *viz.*, *inspection houses* for the superior staff, *quarters* for the petty establishment, *huts* for the canal patrols, *offices* for the revenue staff, and *watering places* for the live stock of the country the channels pass through. A room for a *telegraph office* can be set apart in whichever of these buildings is most convenient for the purpose. At important centres a separate telegraph office is essential.

As the health and, consequently, the efficiency of the establishment depend in a great measure on the style and locality of the quarters they have to live in, it will be well to devote care and attention both to design and situation, so as to ensure a suitable selection and an appropriate shelter from the vicissitudes of the seasons.

It is unnecessary to enter into any details of design of houses here, as these must depend on the locality and the materials available; but the following considerations are always of importance:—

The sites should be high, near good water and proper supplies of food and fuel. They should be central as far as regards necessary inspection of works and irrigation details. Headquarter sites ought to be near the civil station of the district, both for facility of reference to authorities, and because a reasonable amount of relaxation is necessary to all the staff to preserve a healthy mind and body.

Inspection houses should not be spaced too far apart. Inspections to be practically useful necessarily take time, and if an officer has a long journey on a hot day before him he will be inclined to hurry over matters —8 to 10 miles is certainly the limit of distance between houses.

Zilladar's or revenue offices should be at the headquarters of Sub-Divisional charges of the canal, and have ample and proper arrangements for storing records.

Huts are required to house the patrols who hold charge of sections of outlying distributaries. These should be situated near but not in large villages, and should contain sufficient accommodation for the patrol's family, as it is absurd to expect a man of this class to occupy these quarters apart from his family for long periods : and if the patrol lives in the

village he will be unable to preserve that independence of character which is essential to the proper discharge of his important duties.

Watering places in a dry country, being necessary for the large herds of cattle grazed on the country adjoining the canal, will certainly be made by the people themselves in defiance of canal rules and to the detriment of the banks, unless the Engineer provides proper facilities in the shape of metalled *ghâts* down which the cattle can walk, to drink standing in the water This form is preferable to drinking troughs, in consequence of the cattle in India being accustomed to watering in tanks near the village on their way home in the evening.

Watering places will be expensive to construct on the main canal and may be omitted, except near large towns, on distributaries they can be economically built and will be much appreciated by the people

If the watering place is made as a *ghât* going down one bank and up the other across the distributary, its construction may occasionally save a bridge but such *ghâts* are liable to cause silt deposits and are always inconvenient for ordinary traffic The simplest plan is to dig the earth for the bridge approaches so as to form a tank in a convenient spot near the bridge and supply this tank for watering purposes from an outlet of the distributary.

A plank or the squared trunk of a tree simply laid across a small irrigating or drainage channel is often a much appreciated accommodation work. It is financially impossible to provide bridges everywhere the lines cross foot paths convenient to the village community. It is equally impossible to stop the traffic without great friction between the canal establishment and the people, and the stoppage, if enforced, will be a public inconvenience, yet these small foot-paths through a distributary seriously injure its efficiency, spoil the banks and are often the cause of breaches This may appear a small matter, but it is one worth attention

45 **Miscellaneous works**—*Mills for grinding corn, husking rice,* &c., may be advantageously established wherever there are falls on the canal, particularly if in the neighbourhood of a town or large village A separate channel should be cut for the mill race joining the canal again below the fall

The canal water power may also be very suitably employed for the *preparation of materials such as lime, timber, ballast or surkhi* either* for use on the canal works or as a miscellaneous source of income.

* *Surkhi* is pounded brick used instead of sand as an ingredient of mortar.

Permanent weirs and falls on a canal are well adapted in an engineering sense as sources of water-power which can be utilized and the water again passed back into the canal at a very small expense of construction, and a positive advantage to the canal works in the saving of wear and tear. That the power thus economically available has not been extensively utilized is probably due to the weirs and falls being generally situated in places unsuitable for commercial enterprise, to the objection that the power is liable to sudden cessation from closures of the canal for repairs, or for want of demand for irrigation, and to the somewhat illiberal terms and conditions demanded by Government for the use of the power.

An estimate of the loss to the State by this waste of power may be formed from the fact that in the first 50 miles of the Ganges Canal alone some 50,000 H.-P. is available for use, and there can be no question that the objections mentioned above could be easily overcome by suitable arrangements being made for running supplies as regularly as possible, providing a reserve of steam power for emergencies and the transmission of the power to commercial sites by electricity, &c.

Workshops of a somewhat extensive nature will be required to assist the first construction of the canal, unless the work necessary can be more conveniently and economically carried out in existing shops or by commerical firms. It will rarely be found expedient to maintain the special workshops when the canal is completed, but small shops can be profitably maintained at convenient sites on running canals for minor repairs of the plant in use.

46. **Plantations.**—Plantations on both banks of main canals and large branches, are usually provided to occupy the spoil banks, supply timber and fuel for canal works and for sale, and also to give a shelter from the sun to the inspecting establishment and the public using the canal roadways. The spread of irrigation has a tendency to reduce the area under timber in the country generally, by increasing the value of culturable land, and the counteracting influence of the canal plantations is thus a public benefit in itself. The propriety of equipping distributaries with shade lines is a moot point, the sole objection being that the adjoining crops suffer from the shade; but on the other hand travellers passing on the banks, which are always used as a public highway, benefit greatly, the timber is useful on the works in many ways, and compensation for the injury caused by the shade would not be a heavy item.

As considerable expenditure is necessary to provide and maintain a plantation over a long canal it is necessary to work it on a proper system, so that the returns may compensate for the outlay and the rotation of growth and removal of produce be regular and continuous.

Selection of species — The operations to be undertaken will be modified by the demand if this is for fuel alone then trees indigenous or suitable to the locality should be selected and sown Protection *from cattle grazing* is necessary at first, and regular thinning until the trees reach maturity when they can be cut out by blocks and replaced in the same manner

If the demand is for timber alone, or in great part there is a distinct opening for experimental work the suitability of all likely species should be carefully tested both by observing the growth of selected specimens and by chemical examinations of the soils A start can be made with species the suitability of which is known, but the advantage of introducing new and valuable timbers to the country should not be overlooked. The trees should be planted in a regular manner, but closer together than they can be allowed to remain when mature, as they increase in size, the weakly and imperfect specimens should be thinned out by degrees this is necessary, as trees are nourished by proximity in their earlier stages Protection from grazing is imperative for some years, and a *moderate* amount of pruning advantageous

Plantations composed of groups of the same species thrive best, but when the demand is for a mixed product, such as timber, fuel, poles and bark, it is commercially advantageous to plant so as to produce what is required, and in this case the timber trees should be placed the distance apart they are intended to remain until they reach maturity, imperfect specimens or failures being replaced. The intervening spaces can be thickly sown with other kinds

The *fencing* of canal plantations is always a difficulty owing to their small width and great length, which make a sound permanent fence expensive Hedges of thorny shrubs, aloes (*Agavi vivipara*), and bamboo have been tested but are liable to breaks in continuity and tedious to replace Wire is expensive and difficult to maintain, and wood decays very soon. Good results have been attained with aloes planted on a high steep bank with a ditch on the outside, but facility for inspection must be provided Probably the best system to adopt is to give the cattle owners an interest in the progress of the plantations by allowing the

falls to effect alteration of level *tail works* as *escapes, profiles* and *bed marks* for the confirmation of the channel, and *outlets* to distribute the supply to the village *water courses*

From the remarks on alignments it will have been seen that distributary channels ought never to interfere with drainage unless the latter has been artificially diverted from its proper direction Works for passing drainage need therefore hardly be considered as essential parts of a distributary when it is unavoidable drainage can be passed across by a culvert a syphon or an aqueduct according to its level relative to the distributary bed Drainage should never be passed into a distributary

48 **Water courses** —On *water courses* the only works required are those necessary to avoid waste of water at the crossings of roads and to confirm the bed levels

Crossing works are generally made of 9 to 12 inches diameter galvanized iron or earthenware pipes laid in puddle or concrete with or without masonry terminals As the roads crossed are mostly village tracks they are rarely embanked and often worn below the country level, and as it may interfere with the flow of drainage to raise the road the crossings are frequently subjected to a head of water and act as syphons The tract over the crossing ought to be protected from wear by hard material or metalling and the banks of the water-course strengthened near the terminals

These small works are subjected to considerable wear they are isolated not subject to constant inspection and very large numbers are required to maintain the water courses efficiently and prevent waste It is therefore a matter of the first importance to make the designs both cheap easy to construct and lasting in nature

Under existing rules and custom the alignment construction and maintenance of water-courses are practically in the hands of the cultivating classes although it is incumbent on the canal officer to intervene in certain cases The great importance of efficient distribution of water demands a thorough reorganization in this respect and it is absolutely necessary that the alignments and original construction of water-courses with their works should be carried out under proper engineering supervision and with as much care as is now devoted to the main canal and its distributaries The water-courses should also be completed before the canal is considered ready for opening and not be deferred until irrigation has already commenced in a slovenly manner *Without the provision of proper water course channels no canal system can be expected to expand properly or to carry the water in the quantity required*

The construction of water-courses by Government does not necessarily imply that the capital of the canal should bear the cost.* The expenditure can very justly be recovered by a rate assessed on the irrigable area which is a known quantity for each water-course, and it is quite certain that this procedure will be welcome to the cultivating classes as long as the work is carried out in an efficient and economical manner.

Water-course channels rarely require bed marks, as the cultivators will clear them so as to maintain the water at the proper level for their own interests; if found necessary, bricks on end at regular intervals will be sufficient.

With the exception of the first hundred feet at the head, where the banks should be strong, the earthwork of the banks of water-courses should be confined to that necessary just to retain the supply safely, say 6 inches above water surface for height and one foot wide. The banks of water-courses are cut when a field has to be irrigated from them.

A reference to paragraph 49, Chapter II, will show the great advantages that would result from the addition of impermeable linings to the channels of water-courses: a very large proportion of the canal supply brought with so much care and expense over long distances is injuriously wasted by absorption in these channels.

49. Distributaries.—The designs for distributary works should follow the same lines as those of the canal works; the strains to which they will be exposed and the duties they have to fulfil are similar, though not so intense. As large numbers of these works are required, there are many advantages in designing on standard plans; this saves unnecessary labour, ensures the adoption of suitable types and simplifies the supply of materials and plant.

To work efficiently and prevent silt deposits the heads must be skewed to the main channel and arranged to admit surface water only when not fully open thus regulating gates (*see Plate* VIII), or simply loose planks which can be removed one by one from the top are preferable to gates lifting from the bottom: when they are isolated works, heads should be provided with arrangements for locking the regulating apparatus to prevent unauthorized interference with the supply.

The roadway of distributary bridges should be kept as near the general level of the country as can be managed without unduly obstructing the supply, or causing accumulations of floating *debris* in the channel. Road-

* It is interesting to call to mind that the distributaries on the Ganges Canal were at first constructed by cultivators on *taccavi*—*i.e.*, loan advances by Government.

ways supported on iron or mild steel rolled beams are suitable, but generally more expensive than arches High parapets are liable to injury from carts and a broad strong curb from 1 foot to 15 inches above the roadway will be sufficient protection for channels up to 10 foot bed width It is advantageous and not very expensive to curve the land wings as this gives a good entrance to traffic, bumping posts are, however, always required

Solid floors are generally unnecessary for distributary bridges, but masonry bars should be built to bed level, and the intervening space packed with grouted pitching

Ten to twenty feet in length of dry pitching is required above and below bridges, and it is advisable to carry this up the slopes to above water surface Falls can be built combined with bridges with great advantage The cills should be placed above so that the fall of water will be clear of the bridge

When the arch of a bridge is depressed so as to be below the water surface the bridge is called a syphon. This arch must be heavy enough to resist the upward pressure of the head of water, cills are required above and below at channel bed level A fall can be given through a syphon, but there will be severe action at the exit which will damage the banks unless this is checked by special arrangements Syphons are liable to be checked by floating *debris* and are, therefore, more or less objectionable when isolated works though sometimes inevitable on depressed roads, where the country drainage has been artificially diverted across the watershed and cannot be otherwise disposed of

Distributary falls should have vertical cills with notches to regulate the supply and solid floors long enough to take the severe action of the falling water, with wings parallel to the distributary centre line, stepped down beyond the floor to protect the banks below from wash The up-stream wings should be transverse to the centre line and taken well into the bank to prevent the fall being turned by creep—a puddle apron above is an advantage with falls above 3 feet drop The whole structure should be founded on a solid level concrete base, and well pitched above, below and on the banks. A foot bridge over falls is always desirable, it affords additional communication economically, and helps to strengthen the work if placed between the high lower water wings

As the *tail work* of a distributary will usually be situated near the junction of two drainage lines it can be used as a minor escape, if these are capable of carrying the discharge without injury to crops Distributaries

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thus equipped are valuable reliefs to the main line when demand suddenly ceases, and are also saved from the ill-effects of disposing of their own supply through outlets where there is no demand at the time. The capacity of the channel in the last few miles will be very limited if constructed for the irrigating supply only, and when it is intended to pass escape water from the higher reaches the banks should be designed thrown back with broad berms just above the level of the irrigating supply, so as to be capable of carrying both the maximum and minimum volumes with efficiency. (*See Fig 84, Plate* XVI).

Tail works should be provided with masonry falls to the full depth of the bed of the drainage line into which the discharge has to be conducted. The most important work connected with distribution is the *outlet*, and as many thousand isolated works of this class may be required on a large canal it is evident that the determination of the standard design is a matter of importance.

50 **Outlets.**—*Modules*, meters or outlets adapted to measure varying quantities of water discharged are not suited to the conditions of irrigation in India, where it is the invariable custom to charge rates on the crop area irrigated; and as the virtual object of the irrigation system is to produce a crop and thereby ensure the land revenue demand, it would manifestly be a backward step to throw the onus on the cultivating classes by charging fixed rates for water by quantity and making them responsible for the crop. Furthermore, the institution of a system of measurement of this nature would require a complete change in the existing arrangements for the control of the supply in times of slack demand, and would involve a meter to each separate consumer, or a farming out of the supply from each meter to contractors, a course certain to result in great hardship to individuals.

What is required is a series of outlets in each distributary arranged so that each will deliver its full calculated discharge at the ordinary full water surface level, and that the discharges of all outlets will be proportionally reduced as the surface level is reduced. This arrangement provides equitable distribution without any interference by the canal establishment—which is an important advantage to the irrigating community.

This equitable arrangement of discharge cannot be maintained perfectly in an earthen channel carrying silt and floating *débris*; but it can be fairly approximated to by selecting one size of pipe, making this the unit, and fixing one or more units at that level below the high water surface that

will give the required full discharge * The unit generally adopted is a circular pipe 6 inches internal diameter Outlet pipes may be of cast iron, galvanized steel, earthenware, or any other suitable material, but it is of great importance to lay them perfectly level and uniform through out, otherwise the correct volume will not be discharged If the pipes are of earthenware in short lengths they should be laid in puddle, or concrete, the latter is preferable Outlet pipes should occupy the full width of distributary bank and be provided with masonry terminals.

The terminal on the channel side should have a shutter to allow of the outlet being opened or closed, a number for record, and may with advant age be stepped down to facilitate visual estimations of the depth of water in the channel during inspections These terminals also serve as channel profiles. The country or down stream terminal need only be a vertical masonry wall, with a short floor below it to show the correct level of water-course bed. Both terminals should be built with tops at the same reduced level to allow of measurements being made of the head of water acting on the outlet

The water course channel for 100 feet away from the outlet should be a Government work, and have a masonry profile at the end to prevent the discharge of the outlet being increased by lowering the bed of the water course close to the distributary.

The Engineer in charge of the construction of outlets will have to make special arrangements if he expects to have these works correctly built, it is certainly judicious to leave the banks unmade at outlet sites until these works have been built and checked

51 **Well works.**—The importance of keeping alignments clear of *debarred* tracts has already been noticed. It will not be possible, however, to avoid cutting off part of the area commanded from wells now and then. If this is due to the canal line the only remedy possible is the construction of a new well, unless it is considered preferable to provide water from the canal itself for the area isolated

When a distributary or water-course line has to be run between a well and the area allotted to it, a galvanized iron pipe should be placed over the channel as an aqueduct, or an earthenware pipe under it as a syphon to carry the well water This is necessary even with water courses, as

* The difficulty of getting outlets built accurately to varying heads in order to give the required discharges is so great, that it has been found more satisfactory to use pipes varying from 3 inch to 6 inch internal diameter, and keeping all outlets in a given reach the same height above the true bed level of the distributary

both canal and well irrigation may be in progress at the same time, and it is most important to keep both systems clear and distinct of each other.

52. Distributary earthwork.—The earthwork of the main canal will be carried out by the usual rules for this class of construction, but as distributaries are constructed for the improvement of the land lying close to their banks, as well as the more distant part of the doab they command, it is most desirable, and indeed necessary, to avoid, as far as possible, the damage which would be caused by deep borrow pits or heavy spoil banks.

Before entering into details regarding the best methods now followed for excavation of the channels and consolidation of the banks, it is necessary to point out how the necessity for a large excess of earth beyond that which can be supplied from the channel may be avoided.

Unless circumstances demand a special course, it is usual to vary the width of the banks of a distributary in proportion to the bed width of the channel: thus, a large major line will probably require a cart road along one bank and a riding path on the other. Lines carrying moderate discharges always have one bank at least wide enough for riding, while minor lines are, as a rule, only provided with banks sufficient to stand the weathering effects of the rainfall and foot traffic. On minor lines a riding path for inspection is often provided on the country level outside the banks. This course is also followed on large lines where dips in the watershed necessitate an embankment for the channel.

It is also usual to increase both the height of the bank above the channel water surface and the width in proportion to the discharge, in order to diminish the chances of a breach of the banks. A breach in a small minor channel is easily closed and can do but little damage. On a major line the case is far different; not only may great loss be caused to cultivators, but the large area which is certain to be flooded will render the provision of earth for repairs of the breach both difficult and expensive.

Now, bearing in mind this proportion of the dimensions of banks to channel, it will be found that if the water surface in the distributary is kept slightly above the ground level (as it should be kept, to fulfil properly the requirements of irrigation from a distributary on the watershed), the inside excavation will supply just about the proper quantity of earth for the banks when the channel is well proportioned for hydraulic purposes.

It has been shown before that the bed line can be kept fairly parallel to the ground surface. It is, therefore, in the power of the careful designer to fix a depth of excavation for each change of cross section in the

channel which will provide as nearly as possible the proper quantity of earth to make the banks In the Tabular Earthwork form, *Plate* XVII, this depth of *excavation is termed the ' economical digging*," and it is advisable to calculate it out for each change of cross section before laying down the bed line on the longitudinal working section.

It is not possible with an uneven ground surface, and all surface contours undulate more or less to adhere strictly to a particular depth of excavation But a knowledge of the *economical digging* will help the Engineer materially in adjusting the bed line to the best position and the time and care bestowed will be well rewarded by economy in construction, neatness of the completed work and the knowledge that no more culturable land has been injured than was absolutely necessary.

In order to avoid high spoil banks, distributaries should be aligned with great care in undulating ground Before the section is plotted on paper it is almost impossible for the Engineer laying down the direction to tell whether he is taking the line too high or not A trial section would, of course, remove this difficulty, but the best procedure is for the Engineer, in the first instance, to lay down his line strictly on the watershed, and after he has plotted it in this position, and laid down the proposed bed, to remove it from high elevations or *kheras** to contour round them, which will give the *economical digging* It will be borne in mind that such situations occur but rarely in irrigable tracts, and that as the high elevations cannot possibly be irrigated direct from the distributary there is no possible object in plunging into deep excavation which is certain to be not only expensive but very difficult to maintain.

When removed to a side contour in elevated country the channel will be in sidelong ground, and the high side must be protected by the construction of a catch water drain *this precaution should never be omitted*, even when the side slope is very slight

Distributary channels in earth are generally dug of a trapezoidal section with side slopes of 1 to 1 A depth of water equal or slightly less than half the bed width will give a good hydraulic discharging section for widths of 10 feet and under above this width a less proportion of depth to width should be given †

When the channel has been running for some time it will be found that the 1 to 1 inside slope will be eroded at the base, and grass growing near the surface level will catch silt and alter the section to a form

* Mounds formed by the rebuilding of villages on the same sites for long periods

† Some authorities hold that low depths reduce percolation and silting, *vide* Punjab Irrigation Branch Paper, No 7 and note on paragraph 24, chapter V

approximating to a ½ to 1 slope. This growth, with channels running regularly, necessitates clearance about twice a year, and it is then usual to trim the sides to the ½ to 1 slope, increasing the bed width so as to give a wet area equal to that originally provided. Strictly speaking the discharging capacities will differ slightly; but the approximation may be accepted safely in view of the varying values allowed for co-efficients in discharge calculations, and the practically undetermined losses from percolation and evaporation.

Fig. 85, *Plate* XVI shows the original section to which the distributary is dug, and by dotted lines the ultimate section which it will assume after running for some time; the shaded portions are the silt berms. It might appear simpler to dig to ½ to 1 in the first instance: but few soils would stand at this slope in excavation and none in embankment, until consolidated by action of silt-laden water.

Figs. 86, 87, 88, 89, *Plate* XVI show different types of distributary cross sections. The advantage of *economical digging* is noticeable in *Fig.* 86, and the great expense of heavy embankments and deep channels is shown in *Figs.* 87 and 88.

In heavy embankment outside berms (*Figs.* 87, dotted lines) are often necessary. This system is cheaper than an increase to the whole width of the bank, and quite as efficient.

The top widths shown in the diagrams are only suitable for good earth and a moderate rainfall; for sandy soils, liable to weather or cut into ravines, wider banks will be required.

The outside slopes are shown as 1½ to 1. This is the steepest slope allowable; 2 to 1, or even flatter slopes, are often found necessary.

In deep cutting, berms are required to preserve the slopes from injury. They are liable to fall in from under-cutting by the water running in the channel, to be cut into ravines by the direct action of the rainfall, and to slip by being softened and overweighted by percolation from the rainfall on the adjoining country: berms partially prevent injury, and facilitate inspections and repairs.

It is difficult to dispose of the spoil from deep cuttings without throwing land out of cultivation. The best plan is to take up the area of land required as a temporary measure and spread the spoil over it in layers from 1 foot to 2 feet thick: the weathering effects of the atmosphere and the rainfall will render the spoil culturable in a couple of years, when the land can be returned to the owners.

Puddle being usually required in sandy tracts is expensive on account of the distance from which it is necessary to carry the clay; the necessity for its employment should be carefully worked out before it is included in an estimate.

Before commencing excavation it will be necessary for the Engineer to lay down the side width and land boundaries, both permanent and temporary. These are all fixed by direct measurement from the centre line.

Fig. 89 shows the side widths which should first be laid down—AA for the channel square excavation; BB for the permanent land; CC and CC for the temporary land. The measurements for these widths can be read direct from the Earthwork Tabular form; but it is necessary to leave a berm of at least 10 feet wide between the permanent and temporary land on each side of the distributary. This is to lessen the danger of percolation and to encourage the early ploughing up of the temporary land after the borrow pits have been dug. At the time the side widths for temporary land are being marked the sites of outlets or openings for village water-courses should be identified from the section, and a width of 10 feet on each side of the water-course centre line should be left free from borrow pits. If this is not done the borrow pits will require re-filling when the water-course is under construction. Although it is usually unnecessary to acquire more permanent land than that occupied by the channel and banks, yet, as a strict adherence to this rule would necessitate constant small changes of width, it is best to select mean widths for fairly long lengths, taking care that the banks are always inside the width selected.

To avoid dispute regarding the ownership of permanent land it will be necessary to fix permanent marks on the boundaries. Masonry pillars or stone posts at intervals are often used; but the simplest and most economical expedient is to build the outside walls of the water-course heads and the furlong, mile, and other distance marks on the boundaries. Stone posts can be easily altered in position by fraudulent cultivators.

All side widths, as well as the centre line, are marked by lockspits. The centre line, and the permanent land require trenches at least 1 foot wide by 6 inches deep: the other side widths may be marked with nicks $6'' \times 3''$, except where the soil is very light or sandy.

Borrow pits in temporary land should never be dug more than 1 foot deep. With the distributary line carried strictly on the watershed, and a few side cuts to facilitate drainage, this depth will rarely cause excessive dampness or prevent the land being ploughed up for the first crop which

can be sown after the earthwork is completed Deep bare irregular borrow pits detract greatly from the appearance of a new work, particularly when it is borne in mind that they injure the very land which the work was designed to benefit.

Borrow pits 6 inches deep have been recommended but are unsuited to Indian cultivation, where the upper 6 inches of the soil is generally the most fertile and they are expensive both from the large area temporarily thrown out of cultivation and the long lead this shallow depth involves

It is sometimes advisable to dig deep pits for the supply of earth in dry tracts near village bridges to provide cattle watering places These tanks should be supplied with fresh water from the distributary If kept in proper order they are usually appreciated by the villagers and save the distributary banks from injury by cattle *ghâts*

It often happens that earth for banks may be obtained from knolls and by levelling irregular ground, where possible this course should always be followed as it avoids injury to the land borrow pits and often adds to the culturable area near the distributary

The following operations are now required to complete the earthwork of the distributary, they are given in the order in which they should be carried out —

Transfer of surface levels to the bed
Making profiles
Excavation of centre rectangle
Excavation slopes
Raising and consolidation of banks
Dressing and turfing
Check levelling

The surface levels are transferred to the bed according to the depths of digging in the longitudinal section A length 4 or 5 feet of the channel is dug on the square to the proper depth, slightly in advance* of the ground B M or peg the depth being measured with a levelling rod and mason s square (*See Fig* 93 *Plate* XVIII)

The bed level may be fixed either by a temporary peg or a permanent bed mark The latter course is the best because temporary pegs being liable to displacement will entail the necessity of preserving the ground level marks for checking purposes until the earthwork is

* This places the bed mark in advance of its true position this sl ght error may be accepted or the level pegs may be fixed so as to allow for the deviation in the first instance

completed—often a difficult and inconvenient matter. Although many distributaries have been constructed with half furlong or even furlong bed marks, it is well understood now that bed marks at every 100 feet are necessary for proper maintenance of the bed levels. The pipe with disc (see *Fig.* 92, *Plate* XVIII) may be employed with advantage for this purpose. It should be fixed in the manner described for its use as a bench-mark, care being taken that it is in the true centre line of the channel as well as at the exact level of bed. The disc should be marked with the ultimate width of bed (slopes at ½ to 1): this record, always present on the exact spot where it is required, will be found very useful in the future. Other forms of bed marks are used, such as wedge-shaped bricks, brick or concrete bars and wood stakes. An excellent but very expensive form is shown in *Fig.* 94, *Plate* XVIII. This gives both the bed and surface water levels; it is built of masonry on a concrete foundation, of the full section of the channel, with hard brick edges projecting on the slopes at each foot of vertical height from the bed. This bed mark or masonry profile may be used with great advantage at 5,000 or 10,000 feet distances for distributaries, with the intermediate bed marks of pipes and numbered discs.

When the bed of a distributary is in embankment the bed marks should be fixed above ground, and earth rammed round them to prevent disturbance during the construction of the channel. When the embankment is one foot or less in height, pipes alone can be used, but for greater heights a masonry or concrete foundation should be added on which to bed the pipe.

It is best to fix all the bed marks in the first instance with careful supervision. This can be done with great accuracy; but it is work that cannot be hurried over, and if for any reason it is necessary to push on the construction of the distributary it may be expedient to fix the permanent bed marks at the 1,000-foot intervals and only to dig pits to the proper depth at the 100-foot intervals, or experienced contractors may be given a list of the depths of digging.

When the permanent bed marks are not fixed at first, they should be put in after excavation of the channel but before the bed is finally cleared. This can be done with a level and staff, the 1,000-foot bed marks being used as reference: pegs are driven in first to the proper depth, *viz.*, to the slope of the bed between the 1,000-foot bed marks, and the pipes and discs fixed with the mason's level afterwards. Boring rods are also used to fix intermediate bed marks, but they are not reliable for long distances.

When the fixing of bed marks has advanced for some distance from the distributary head a party of experienced labourers may be started on profile work This consists in cutting the interior slopes of the channel when in excavation for about 5 feet in length opposite each bed mark, and in making up the banks for the same length As these profiles are intended to act as guides to the contractors when constructing the distributary great care should be bestowed on the style and accuracy of the work, the excavated slopes must be neatly trimmed and the embankments thoroughly consolidated with the proper slopes It is a good plan to allow each contractor to make the profiles in the length of distributary he is to construct, he will thus early learn the style of work the Engineer expects from him and gain an insight to the rates, etc

Cord instead of earthen profiles are sometimes employed, they are suitable for high banks but are liable to displacement, and should be checked frequently

A bevel plumb rule should be used to check the accuracy of all side slopes as workmen, if not carefully looked after are liable to round off interior excavated slopes making the top width and bed measurements correct (*See Fig* 95 *Plate* XVIII)

The making of profiles completes the preliminary operations, and when they are ready over a sufficient length of channel the earthwork should be carried on with vigour This is expedient to avoid the unnecessary occupation of temporary land and time of supervising establishment, and to ensure the earth being consolidated when it is freshly excavated and before it has had time to harden The centre rectangle should first be excavated with vertical sides (*see* AA, *Fig* 89), the earth being thrown on the bank space in 6 inch layers, all clods being broken up and grass and jungle removed If the bank space is covered with thick grass or jungle it should be cleared before the earth is thrown upon it, each 6 inch layer should be laid to the full bottom width of bank and thoroughly consolidated before a second layer is put on It is advisable to make each layer extend over a considerable length and to generally carry on the earth work of the bank as level as possible because short uneven lengths of bank are difficult to consolidate properly This is particularly necessary where banks are rolled instead of being rammed

When the centre rectangle is completed on a sufficient length the interior side slopes may be dug out and trimmed Contractors generally keep their best men for this work, it is difficult to execute neatly but profitable to the workmen, as the vertical sides can be cut down in lumps

into the centre channel.* Frequent inspections of the work are necessary to prevent these lumps being buried unbroken in the banks, but bad work like this cannot be concealed if the rule of long lengths of 6-inch layers is adhered to.

The banks may now be completed to the full height of excavation from borrow pits in the temporary land. If the consolidation is properly carried out it is not necessary to make the banks over full height to allow for settlement. It is usual in estimates to provide a certain sum for maintenance during the season following construction, and this sum should be sufficient to raise and widen banks where they may have settled. These remarks only apply to well-designed sections; in heavy embankments the usual allowance should be made.

In ordinary agricultural land the outside lockspits for borrow pits need only be laid down as the work proceeds; this will allow of many improvements being made by carefully selecting the sites from which to take earth. In gardens or valuable land great care should be taken in this respect, and it will be better, and often cheaper in the long run, to carry earth from a long distance and avoid injuring valuable property. Compensation should always be paid for any injuries caused. The amount can often be reasonably settled on the spot by the Engineer personally, or a trustworthy subordinate, and this will be found more economical to Government and satisfactory to the people than an appeal to the courts.

The best season for outside excavation is after the rabi is cut, finishing in the beginning of the rains; interference with crops will thus generally be avoided, and the compensation payable for temporary land be reduced to a minimum. If the outside lockspits for temporary land are not laid down until actually required, the rabi harvest can be cut by the cultivators and the borrow pits dug, and the land returned to zamindars in time for the kharif sowing.

The banks at works should not be thrown up until the masonry is completed and passed. This is particularly necessary for small works such as outlets, and it is advisable to omit certain lengths of bank at works from the earthwork contract and to include them in the Works Estimate at special rates.

* When work is carried on in a dilatory manner, particularly in warm weather, the soil exposed to the hot wind gets very hard and lumps carelessly allowed in the banks cause frequent breaches of the distributary. In time the banks get sound to normal water level; but every unusual rise of water surface finds weak places, necessitating frequent and expensive repairs, and it sometimes takes years to put a badly-constructed bank into good condition.

There are three systems of consolidation—with rammers, rollers, and by water for the two first systems 6 inch layers and the breaking-up of lumps and clods are essential

Ramming with iron *durmuts** is fairly effective if properly carried out in 6 inch layers when the soil is freshly excavated, damp and soft, on hard earth in foot layers it is quite useless It is, however, notoriously difficult and this is very expensive on long lines of small cubic capacity like distributaries On broad banks, earth in 6 inch layers can be well consolidated by making the work people walk over each basket full of earth they throw down, but this system cannot well be applied to narrow banks

Rolling is an excellent system with damp earth, but contractors do not always take to it. The rollers are best made up of a number of mortar mill stones about 2 feet 6 inches diameter and 15 inches wide, these stones have a 6 inch hole in the centre and three or four are drawn over the bank together by means of a loose axle passing through the centre holes They can be drawn by men or bullocks, but men work best as they are available on the spot at the proper time and the number can be varied to suit the condition of the bank

Generally speaking, rolling is best for heavy clay soils and ramming for more sandy The cost of rolling is actually less than the expense of thorough ramming, but contractors prefer the latter system as they well know that the specification can rarely be enforced.

The Engineer when inspecting banks, if in doubt regarding their soundness, should cut sections through them at different places

Consolidation with water is the most satisfactory, but a troublesome system and not always possible. The banks may be thrown up to their full height, but should not be dressed off Water should then be passed into the distributary, and stop-dams made at intervals, the water can either be baled up on the banks or led along their tops in narrow channels After the banks have been thoroughly soaked they can be trimmed off to the proper section The water standing in the channel will injure the inside slopes a good deal, necessitating a second dressing off but this small expense will be amply repaid by the compactness the banks will attain and the rapid growth of grass on them

When plenty of water is available it may be used to irrigate the temporary land before the borrow pits are dug, this will improve the banks if the earth is rolled or rammed before it dries

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* Earth rammer

Distributary banks should be neatly dressed off to the proper section, and maintained so until grassed over. The expense of turfing is prohibitive for small sections, but a good growth of *dub* grass can generally be ensured by watering the new banks and careful weeding. During the hot weather and rains, when the *dub* grass is well established, the banks should be let for grazing throughout the year. Grass-cutting with the *kurpah* should also be encouraged, as this process improves the *dub* growth and kills off other grass. Some canal officials object to cattle being allowed on distributary banks; but it will be found that their trampling consolidates the banks, and the saving of the cost of annual jungle: clearance will more than cover the expense of repairing the slight damage they do.

The preservation of earthwork in good condition is as important as its construction at first in a proper manner. When distributary banks are let for grazing the contract should be drawn out with care, so as to provide against malicious and careless damage. Unimportant stipulations, and those practically impossible or very difficult for the lessees to comply with, should be omitted. It must be borne in mind that owing to the length of the channels, and the heavy charges held by responsible officials, inspections are necessarily infrequent; and, no matter how stringent the rules against grazing may be, cattle will wander or be driven from the dry plain to the green canal bank. It is, therefore, better to accept the situation, avoid worrying litigation, and at the same time remove an engine of constant oppression of cultivators from the hands of the sometimes over-tempted petty Government servant who, in the absence of a senior officer, may have full control of the regulations.

Regulated grazing, with ample facilities provided for traffic crossings and watering, will do much in the way of preserving distributary earthwork in sound condition,

The discharge of a distributary is fixed by the total of the discharges of the outlets from the tail up, *plus* in some cases an assumed tail escape discharge; the area of cross-section, therefore, is regularly decreased from the head to the tail.* The reductions of section should take place immediately below each outlet, and as the outlet discharges are small compared with the distributary discharges the reductions will be usually very small, often only a fraction of a foot of the bed width.

The bed widths at side slopes of ½ to 1 are shown, as previously stated, on discs (to the nearest tenth) by the 100-foot bed marks. Now, it is quite certain that no amount of supervision will ensure berm-cutting to

* *Unless, of course, the slope of bed is changed.*

this degree of accuracy, yet if the tops of the berms are carefully nicked out to as near the proper width as possible and wood profiles are freely used to guide the workmen the general result will be found a close approximation to the true section

All those who have carefully observed the channel of a river over a considerable length when the increase in supply is given by small affluents, springs or percolation will have noticed the great difficulty of determining the exact points at which the increases of sectional area* occur even when the total difference between the areas above and below are great In canal engineering we cannot err in closely imitating nature, and attention to this point will reduce silting of the bed irregular growth of berm and erosion of the banks It need hardly be stated that these results will only follow when the calculated areas of section and slope of bed are such as to give a velocity suited to the soil and amount of silt in suspension

The care shown as necessary for the supply of earth for banks during construction and for consolidation is required for maintenance and repairs in after years Earth for strengthening banks or closing breaches should be taken from borrow pits dug outside those used for construction, on no account should the old pits be deepened Hollows or breaches in the banks should be opened to the full depth and the sides or slopes stepped back before being re filled Ramming in 6 inch layers should be insisted on, and water freely used for consolidation, and all clearances from the channel instead of being thrown on the banks or berms should be deposited and levelled off in the old borrow pits

The earthwork of a distributary cannot be considered complete until the record section is prepared, this should show the actual reduced levels of the bed marks and both banks Levels are usually taken to the $\frac{1}{100}$th part of a foot and it is manifestly impossible to construct to such a degree of accuracy consequently approximation must be accepted, but as a general rule bed marks should not differ from the true bed level by more than $\frac{1}{10}$th foot and banks by more than $\frac{1}{4}$th foot—differences greater than these should be corrected

The difficulty of correctly and expeditiously estimating and measuring up the earthwork and land over long lengths of distributary at every 100 feet is very great and the work cannot be economically carried out by the regular Earthwork Tables or highly paid establishment A tabular form

* It should be mentioned that the preservation of a proper sectional area will maintain the water surface at the calculated level—an all important matter in a distributary

is appended which can be used with advantage, after a little instruction, by two clerks working together. A few examples are worked out to show the system. One clerk taking the longitudinal section in hand reads out to the second clerk the entries for columns 2, 3, 10 to 12, and 14; an entry of column 3 will be necessary at every peg where the bed is below ground; 14 can only be entered where the bed is embanked, which will seldom occur. Columns 2, 10, 11, and 12 only require noting in the form where these dimensions are changed in the section. After the entries are made they should be checked over, and then the economical digging can be calculated out by trial for every change in any of the dimensions 2, 10, 11, and 12, if this column has not already been filled up as a guide to the engineering of the channel.

When the depths of digging are equal or over the economical it will *not be necessary to carry the calculations* beyond column 8, as the economical depth provides sufficient earth for the banks.

The remaining columns involve simple calculation, and can be directly written down if one clerk uses a tabular multiplication table* or a slide rule, the other clerk entering the results as called out. Columns 8 and 21 only require one entry each for every 1,000 feet.

The land widths can be written down directly from inspection.

From the above the procedure for calculating by this form may appear lengthy; but in practice it is very simple and straightforward work, and most of the entries will be found of great assistance when the work is being set out on the ground.

The great saving in labour due to the form occurs when payments have to be made to contractors. Separate rates of excavation and embankment can be dealt with if necessary, and, calculations at 100-feet lengths for small sections being quite accurate enough for direct payments, all measurements on the spot of work done can be dispensed with. The Engineer is thus relieved from many laborious and wearisome days in the field and office.

53. **Drainage operations.**—No project for a canal is complete unless it includes arrangements for the proper disposal of the surface *drainage* of the tract to be operated on. It was mentioned previously that the alignments of the distributaries first constructed for irrigation seriously interfered with the drainage lines. As time advanced the evil effects of this interference were more and more felt; this resulted in the institution of extensive works for the remodelling of the distributaries and the

* Crelles' *Tables de Calcul* is an excellent book for this purpose, its use will save an immense amount of mechanical calculation, or a slide rule may be used.

improvement of the drainage lines. At the present time matters may be considered fairly satisfactory. It may safely be said that nowhere is any serious injury allowed to occur by obstruction of drainage, indeed, at the present day the canal officer looks on the improvement of a drainage line as a more urgent work than the revision of an imperfect irrigation system But the earlier remodelling works often stopped short of a perfect transfer of the irrigating line to the watershed and the drainage channel to the natural depression In some cases the old alignments were adhered to, and the drainage improved by cuts through the watershed and culverts or syphons under the existing distributaries This removed the evils of obstructed drainage, but no system thus tinkered can be accepted as satisfactory, and it will at once be seen that where a distributary line is itself off the watershed every water course fed by it must cross low land to gain the backbone of its minor *doab*, thus covering the low tract with a network of obstructions to the proper flow off of the rainfall

In new works carried out on the information supplied by properly demarcated maps these evils cannot occur The Engineer finds ready to hand not only the course of the drainage laid down most minutely, but the boundaries and area of its catchment basin, and his work may be confined to the estimation of the flow off that area as calculated by the formula most appropriate to the locality, and careful examination on the ground to determine what improvements are required along the lowest line of the depression to enable the floods to be passed on without injury to the land.

It is quite unnecessary to provide a regular channel for each drainage depression. The too rapid removal of the rain water would often cause more evil to the country than even long continued flooding involving the local destruction of crops The depletion of the subsoil reservoirs which depend on percolation to maintain the supply for well irrigation would in time reduce to a desert all the area not supplied by canal water

In most cases it will be sufficient to preserve in a considerable degree the natural conditions which existed prior to the introduction of the canal works, only increasing the facilities for flow off when local information shows improvement really necessary or when it is desired to reclaim flooded land for cultivation. Near the main canal no damage to the subsoil will result from the most perfect drainage, and in all cases it is permissible to reduce the naturally flooded area to the extent of the reinforcement to the subsoil given by the irrigating supply

As minor depressions combine to form major lines, the tendency to a confirined channel may be encouraged by the Engineer until the stage of a regular stream or *nala* is reached.

54. **Discharge from catchment area.**—In order to determine the carrying capacity proper for a drainage depression, channel or work, it is necessary to estimate the probable maximum discharge due to the rainfall. Owing to the variations in evaporation, absorption, and rainfall, no certain rule can be laid down for the Engineer; but the following empirical formula has been laid down by Colonel Dickens, R.A., from a comparison of certain observed data, and until a better one is known this may be used as an approximate guide:

Let M = the number of square miles of any catchment area, no matter how small.

D = its discharge at highest flood in cusecs.

Then $D = 825\,M^{\frac{3}{4}}$.

This formula is only applicable to cases within a certain average of annual rainfall, say of 36 inches in the year. It may, however, be considered to hold approximately in case of 24 to 50 inches of average annual rainfall, as the heaviest fall of rain varies less in proportion than the annual rainfall.

For small catchments the waterway is sometimes fixed by determining the area of opening required per square mile drained. This area may vary from 2 to 20 square feet per mile; it is determined by comparison of the area under examination with the known results from other areas under similar conditions. Thus on the North-Western Railway in Jullundur 7·4 square feet per mile was found insufficient; 9·85 square feet was allowed for the Kali Nadi aqueduct, both of them large catchment areas; on the Gunduck embankments 10·8 square feet was found insufficient, and increased to 13 and 14 square feet, but the basins were small and near the hills.

A greater relative discharge must be assumed from small than large catchment areas. This of course is due to the time which must elapse before the flow-off a distant part of the area can reach any given point; in the meantime the discharge from nearer points has passed away in whole or in part. Some authorities have used the following scale, but it cannot be accepted as generally applicable:—

Area in square miles,	1 to 10, 10—20, 20—50, 50—100, 100—500, 500—1,000, 1,000—2,000, 2,000—3000.
Discharge in cusecs per sq. mile,	80,56, 32, 26, 22, 18, 16, 12.

No formula however ingeniously constructed can cover the range of conditions presented by large catchment basins A torrent with a long course in the hills and then passing through a sandy tract can hardly be compared with a flat depression lying in a saturated country, the rainfall is rarely uniform either in time or quantity over a large area and the length of a basin has a controlling and regulating influence on the floods passing over it

Mr J Craig M I C E has determined a formula* for the discharge from a catchment area which appears to give reliable results—

$$S = 184\cdot2B \times \log \frac{8L^2}{B}$$

Where S = the sectional area in square feet of maximum flood at the discharging point

B = Mean width of area in miles

L = length

The maximum flood discharge can be obtained in the usual way by applying the sectional area found by the formula to the cross section of the stream at the discharging point for hydraulic mean depth and measuring the declivity of bed

This formula is founded mainly on a consideration of the *shape* of the catchment area and the accuracy of the results has been demonstrated by numerous results worked out by the author

To obtain B and L the perimeter or ridge line of the catchment area should be rectified by means of straight lines as CD which with the distances CA and DA will divide the area into triangles with their apices at the point of discharge (*See Fig* 96 *Plate* XVIII)

For each triangle L = the mean length, and B = the perpendicular distance from CA or DA to L *viz* the mean width so that B × L gives the area of the triangle ADC

The sum of the discharges from all the triangles into which it is rectified will give the discharge of the basin

It is always advisable when possible to measure the actual discharge off a selected basin in heavy rainfall as a guide to the scale to be adopted for the designs, the most favourable opportunity is after rain has continuously fallen for several days as the country will then be thoroughly saturated and the flow off a maximum for the rate of fall

55 **Drainage works**—The drainage channel should *invariably* follow the true drainage line Cuts through bends however tempting as

* *See* Professional Papers on Indian Engineering Articles LXXX Vol III XCV and CVI, Vol IV Third Series

shortening the line and economical, are wrong in principle and, as the channels must pass through relatively high land, are liable to obstruct the discharge, causing unnecessary flooding above. Many drainage lines consist of a series of depressions connected by low necks of higher country. Except when it is necessary to improve the drainage, so as to allow of cultivation over the depressed area, the drainage work required will be limited to lowering the necks to the extent necessary to pass off the flood volume in a *uniform* manner without, *on the one* hand, flooding existing cultivation or, on the other, reducing the proper percolation supply to the subsoil. In this case the confinement of the channel through the necks is no evil; the flooded depressions act as regulators on the supply, and the dimensions of the channel can be calculated so as to discharge the exact volume necessary.

When the excavation for the channel is more or less continuous, the curves on the alignments should be laid down with the same care as is required on irrigation channels. The excavated earth should be deposited in low spoil banks, leaving a wide berm and openings for entrance of drainage every few yards, or, if the country passed through is culturable, the spoil can with great advantage be spread on low spots for their improvement.

To prevent the channel being blocked by erosion of the banks, inlets should be built at points where considerable volumes of drainage flow in; these may be simple dry stone revetments, sloping channels lined with masonry or regular vertical falls, as occasion demands.

When there is small perennial flow of drainage, with occasional heavy floods, the channel should be designed with a cunette to keep the bed in good order and prevent the growth of water-weeds, etc (*See Fig.* 97, *Plate* XVIII.)

Drainage channels require a riding path on one or both banks, to facilitate the inspection necessary for proper maintenance. This path must follow the contour of the country, as an embankment would interfere with the drainage inflow; it may have to be diverted away from the direct line when deep hollows are met with, and cannot be kept up in the same style as the paths in irrigation channels, but the inlets must be bridged when they would be otherwise impassable in the rains and the path should be kept practicable in all seasons.

All the works already described as suitable for the conveyance and inlet of water on irrigation works are liable to be necessary on drainage channels, but only to a modified extent. As the discharge is temporary,

higher bed gradients can be given and bars used to protect the bed when erosion is threatened Syphons are objectionable, as being liable to choke with floating *débris*.

It is occasionally permissible to use regulators on drainage channels, or to equip falls for this purpose when it is necessary to store water in village or other tanks for household purposes, or for irrigation in special cases The regulating arrangements in such cases should be *in the hands of the village authorities concerned, but care must be taken* that injury is not caused to adjoining properties

When the course of drainage is improved by Government authority, the channel line should be kept clear throughout, and the area liable to be flooded should also be preserved from cultivation with crops liable to injury from excess of water.

56. Warping works.—The water moving in a river or canal channel carries silt with it in suspension, the quantity varies with the season, the nature of the bed and the velocity Thus measurements made on the Ganges near Cawnpore in 1870 showed for the canal at the tail an amount of silt in suspension varying from $\frac{1}{896}$ in July to $\frac{1}{1696}$ in January, while in the river the differences were still more marked, being from $\frac{1}{582}$ in August to $\frac{1}{35888}$ in March On the Sirhind Canal $\frac{1}{1000}$ solid matter was actually deposited on the bed in August 1897. Simple experiments can determine the amounts of solid matter in suspension at any time, and it is expedient to have this information when warping works are contemplated.

Warping is the act of turning the water moving in a channel from its ordinary course for a certain time, so as to reduce the velocity and thereby allow the solid matter to deposit The period required will vary according to the nature of the material held in suspension

The following rates of fall of silt in still water are taken from the Proceedings of the American Society of Civil Engineers :—

Material	Rate per second inches.
Brick clay mixed with water and allowed half an hour to settle	0·108
Fresh water sand	1·690
Sea sand	2·350
Rounded pebbles, size of peas. ..	12 000

But successful silting tanks could hardly be based on these results, and

it will always be necessary to examine the water at the exits of tanks to determine if the operations are proceeding properly.

The description of warping works on a large scale from rivers is beyond the scope of this Manual. It may, however, be briefly mentioned that there are two distinct classes of works, *viz.*, those by which the whole river or a great part of its supply is diverted from its proper course so as to flow over a depressed area, deposit its silt and return to the regular channel again lower down; and the training works which, by creating still back-waters, compel the deposit of silt and mud so as to raise up to culturable height portions of the river bed from which the main stream has been permanently diverted for any reason. Both classes of works may be necessary and useful, both in an engineering sense for the confirmation of a proper channel for the river, and agriculturally for the benefit of the country generally: and they afford great opportunities to the scientific Engineer, as they involve the proper direction and control of vast natural forces to a useful purpose.

57. **Silt tanks.**—The warping works which more directly concern the Canal Engineer are the *silt tanks* commonly required on canals and distributaries, when the bed of the channel is either level with or above the ground surface, or when the only soil available with which to make the banks is of bad quality. It is not advisable to use silt tanks in sandy percolative soil unless the loss of water is of no consequence.

Silt tanks are compartments outside the regular banks of the channel, confined by secondary longitudinal and cross-banks, and provided with cuts from and to the main channel arranged to act as inlets and outlets for the supply. *(See Fig. 98, Plate XVIII.)*

The silting operations are shown in progress in tanks A, B, and C; D has only just been opened. In A, which is nearly completed, the deep hole near the outlet can be silted up by altering the outlet to an inlet, or closing it and opening a new inlet above: in C the first inlet made has been closed, the winding channel through the deposit levelled off and a new inlet opened. Those shown are only a few of the expedients which can be adopted to promote effective deposit, the main object being to prevent a direct current from the inlet to the outlet.

This system of short compartments is the one generally adopted. In some cases, however, it is preferable to take the whole supply of the channel for long lengths over the area to be warped up. The operations with a single inlet and outlet will be more rapidly completed, and will not injure the regular channel by berm growth; but the after levelling

off of the warped area will involve a considerable amount of work, and except for small channels there may be difficulties and expense in passing the supply into and out of the silting reach

The earth for the banks of silt tanks should obviously not be dug from outside borrow pits, and must therefore be taken from the tanks or the channel bed The objection to the latter site are, that bed pits silt up slowly, increase percolation, cause weed growth and, if long and close together, are liable to affect the slope of water surface On the whole it is preferable to take all the earth required from the land enclosed for warping.

The dimensions to be given to the banks is a question of great importance The outer bank must obviously be strong enough to withstand the head of pressure when the canal is full, and though at first sight the inner banks might be considered as mere partitions and not liable to any severe strain yet, as the conditions of supply and demand for irrigation may render the temporary closure of silting operations at any time necessary, it is certainly judicial to provide banks that will meet this contingency

The efficiency of a silt tank depends on the draw of silt laden water into it The inlets should, therefore, be dug *down to the level* of canal bed, at an angle of 45°, and far enough from the outlet discharging clear water above them to avoid taking this in instead of the silt laden supply, 100 feet apart will usually be sufficient, or adjoining tanks may be run alternately.

Experience seems to show that lengths of from 600 to 800 feet are suitable for silt tanks Very short tanks are expensive to make and work, and bring the outlets too close to the inlets—very long tanks are inefficient The determination of the correct length depends on the time it takes the suspended matter to deposit and experiments on this point should be frequently carried out during silting operations in order to correct and improve the system

Silt tanks should be kept clear of obstructions such as tall grass, bushes, etc These hinder instead of promoting the deposit as they reduce the waterway, creating currents while the tank was constructed for the very purpose of destroying velocity.

At certain times of the year there is very little visible silt in the water, but at such times it often contains fine clay which will slowly deposit, and on the whole it may be accepted as proved that the more regularly and steadily silting operations are continued, the sooner will

the operations be concluded. Constant attention is required to carry on warping with success, the changes in the deposits must be inspected, and the work necessary to promote and increase them at once put in hand. As each reach is completed, it should be levelled off and dressed to the form necessary for proper disposal of the rainfall off its surface, planted out when this is permissible, and generally brought to the conditions required for a properly maintained canal bank.

The reduction in the volume passing down the true channel has a tendency to cause the growth of berm on the banks; it will be necessary to watch this growth, and bring the channel to its proper section as soon as it is to be called upon to carry its full supply. The excavated berms can be utilized to level off the completed silt reaches.

On canals carrying average quantities of silt, throwing the banks back 10′, 20′, 30′, or more as required, has been found a much quicker method of ensuring sound and wide banks in embankments. For reclaiming land at the same time, silt tanks are preferable.

58. **Bricks.**—In concluding this Chapter a word may be said on the subject of the class of brick now commonly manufactured for use in India. It is stumpy in shape, *i.e.*, thick compared with its length and breadth, therefore unsuitable for good bonding; often brittle, owing to too rapid removal from the hot kiln, and too dry puddling of the clay, and it is always when well burnt, covered with a more or less glazed skin to which mortar will not firmly adhere. When masonry built of first class bricks is demolished the bricks will often be found to come away whole, and fit for use in other works; and this result, though economical from one point of view, does not speak well for the strength of the original structure. The old-fashioned large thin flat slop-moulded brick, burnt in a clamp, though somewhat irregular in shape, was tough, and well adapted to give a sound bond, and the mortar adhered with great tenacity to its fibrous surface. In these modern days with a heavy demand for material, it is not possible to revert to old-fashioned, and somewhat wasteful, methods of manufacture; but it is quite certain that the question of the best possible dimensions and methods of manufacture of bricks is one demanding more attention than it has yet received from Engineers in India.

CHAPTER VII

DESIGN OF FALLS AND WEIRS

1 **Falls** —I am not in entire agreement with Col Clibborn on two points in connection with the design of falls—

(i) The undoubted superiority of the V notch over the plain crest under all circumstances

(ii) The necessity of cisterns to counteract the pounding action of falling water

2 **V Notch** —From a purely engineering point of view, to have the crest wall so shaped as to maintain an even velocity of approach right up to the fall, with varying supplies in the canal, is an undoubted advantage *upstream* of the crest As regards the dynamic action on the *down-stream* side this advantage does not hold For economy in design, we want the type of fall which will dissipate the energy of falling water in the shortest length

Drop a perfectly elastic smooth sphere vertically on to a smooth perfectly elastic horizontal floor, and it will come to rest on the spot where it fell, or its energy will have been dissipated in the shortest length Let the same sphere be given some horizontal motion as well as vertical, and it will travel a certain distance horizontally before coming to rest, the distance depending on the horizontal velocity it started with

Our aim in designing falls is to reduce the horizontal component as far as possible, and this is best achieved by having a drop as nearly vertical as possible The nearer it is to vertical, the shorter will be the length of floor necessary for the dissipation of the dynamic energy

There is far less horizontal velocity with a vertical drop and a plain crest than with a V-Notch, even though the latter has a spreader attached on the down-stream side It is impossible for it to be otherwise

The disadvantage of a plain crest is that for supplies considerably below normal, the velocity of approach is retarded to such an extent, that silt deposits on the upstream side, and for volumes in excess of normal, there is liability to scour With an experience of 35 years on the canals in the United Provinces, I can say with confidence that neither of these disadvantages are worth considering

The heights of crest are always calculated for full supply, which is very seldom if ever, exceeded, and then only for a few hours perhaps, and any silt that deposits in low supplies, is scoured out as soon as full supplies are run again.

Next comes *the advantage of automatic regulation for V-notches*, so that if the main canal and branches are properly designed, with a two-thirds supply in the canal, all distributaries will automatically get two-thirds supply and there will be no need to keep up a regulating establishment. On paper as a theory, this is excellent, and possibly in the Punjab there is little or no difference in the demand over a whole canal system at any given time; it is quite otherwise in the United Provinces. As an extreme case I mention the Deoband branch of the Ganges canal, with an allotted discharge of 525 causecs, which year after year is kept running through the rains for rice-irrigation in light loam soil, when there is no demand anywhere else on this big system with a full supply of 8,250 cusecs.

The Asafnagar Falls are planked right up to the top and practically no water goes over, just to be able to feed the Deoband branch. In the yearly returns, the Ganges canal is shown as closed at the head.

This, of course, is an extreme case; but to have a variation of 8 to 16 *annas demand at the beginning of the rabi season, is a normal condition.* The demand in the Mat Branch rising to full 16 annas, before the rest of the canal system has risen to 8 annas.

With such varying demands at certain seasons of the year the automatic regulation of V-notches falls to the ground and regulation by sleepers has to be resorted to.

When we come to special regulation of this kind the plain rectangular crest is far and away easier to manage than the V-notch.

As regards the automatic regulation for outlets in distributaries, the small V-notches, perhaps 6″ at bottom and 1½ feet at the top are a great temptation to the cultivators.

To fill up the V-notch with rubbish is comparatively easy, whereas to obstruct a plain crest 5′ to 10′ long is extremely difficult without planks.

The conditions of demand that prevail in the United Provinces do not lend themselves to automatic regulation by the use of V-notches.

3. Cisterns in Falls.—Cisterns were introduced below falls so as to have a cushion of water at all times to withstand the pounding action of

falling water Mr. Beresford's experiments proved conclusively that there is no pounding action in a continuous stream, but only dead pressure equal approximately to the weight of the column of water

In irrigation canals, where supplies are very gradually increased to full volume on first opening, there will always be a cushion of water on the down-stream side, equal approximately to twice the depth passing over the crest This means that with 6″ going over the crest, there will be a 1′ cushion of water on the down-stream floor, with 2′ going over the crest, there will be a 4′ cushion and so on. These being the actual practical conditions, I cannot see any real need for a cistern, which adds very materially to the cost as the foundations have to be lowered by the depth of the cistern, and in my opinion actually necessitates a longer length of floor, by inducing a standing wave just about where the cistern ends

The Kasimpur Fall, on the Sumera distributary of the Aligarh division of the Ganges canal, was built by me in the eighties with a cistern, as at that time it was the accepted method and always insisted on Later on I was able to obtain sanction to build certain falls without cisterns and as anticipated I found the action below these falls considerably less, and the usual standing wave entirely eliminated

In 1912 when inspecting the Sumera distributary as a Superintending Engineer, I noticed the high standing wave at the Kasimpur fall, and ordered the cistern to be filled up with concrete The result is shown in *Plate* XIX.

My own experience is that a plain crest with a drop as nearly vertical as possible on to a horizontal floor at down stream bed level, and water wings at right angles to the crest, and a few feet further apart than the length of the crest, give far less action below a fall than the old system of cisterns with curved or splayed down stream water wings

4 **Length of protection needed** —In deciding on the length of protection needed below a fall, there are two factors to consider, (i) the height of fall from water surface to water surface and (ii) the volume passing over the crest per foot run of crest

This second factor is frequently not considered. Obviously the dynamic energy of 1 cusec per foot run of crest falling say 10′ is very much less than that of 10 cusecs per foot run falling the same 10′. The dynamic energy in the first case will be dissipated in a shorter length than in the second case

If h be the drop from water surface to water surface, the following ratios may be accepted as safe from actual practice in the United provinces :—

Cusecs. per foot run of crest.		Length of floor.
0 to 5 cusecs	..	$4h$.
5 to 10 ,,	..	$5h$.
10 to 15 ,,	..	$6h$.
15 to 20 ,,	..	$7h$.
above 20 ,,	..	$8h$.

The above are only rough approximations for vertical drops and clear overfalls, i.e., when the full supply level on the down-stream side is below the level of the crest.

5. **Weirs.**—The first point to thoroughly appreciate is that the water held up by a weir has a static head, inducing percolation of a certain portion of it below the impermeable foundations and floor, the head decreasing steadily until it reaches zero at the end of the down-stream impermeable floor where it is free to the air. This water flowing below the foundations, has an upward pressure corresponding to the head; it also has a velocity dependent on the head and the friction it meets with.

The thickness of the impermeable floor must be sufficient for its weight to counterbalance the upward pressure, and the velocity must not be so high as to move the sand below the foundations and so undermine the work.

The approximate hydraulic gradient is from the maximum supply level, with no water on the down-stream floor, beginning at the point up-stream where the floor is permeable and ending at zero, i.e., at the end of the impermeable down-stream floor. The ordinates to the straight line joining these points may be accepted as very nearly accurate measures of the varying static heads on the floor, the ordinates being measured from the *underside* of the floor to the hydraulic gradient line.

The steeper the gradient, the greater the velocity of the percolation water ; the flatter the gradient the less will be the velocity or rate of percolation, and the less its power to undermine the work.

It has been found in actual practice that a hydraulic gradient of 1 in 15 is sufficient to prevent undermining in fine sand. Possibly in soft earth, which needs a less velocity to move it, as flat a gradient as 1 in 18 may be needed, but as fine sand is the worst soil we normally have to deal with, 1 in 15 may be taken as the flattest gradient ordinarily needed. In boulders, from a statical point of view, the Myapur regulator at the head of the Ganges canal, has a gradient of 1 in 2½, and has never

shown any signs of undermining This is not surprising, as it needs 20 times the velocity to move 1′ boulders that it does to move fine sand

Dynamic considerations will probably limit the gradient even in boulders to 1 in 7.

An example will explain the principles involved better than much writing. A weir has been built with crest 6′ above bed of river and foundations 8′ below bed, of material twice as heavy as water There are no gates on the crest, with floor as in sketch, and no up-stream apron.

The upward pressure at D is something under 12′ head of water, so that the floor thickness of 6′ is ample to balance this head After a few years of working it is found desirable to increase the command and to add 4′ *high drop gates on the weir, raising the full supply level by* 4′ The approximate loss of head due to the extra friction in getting under the 8′ deep foundations is allowed for by starting the hydraulic gradient at G, a point vertically above F, taken 8′ distance from the weir. The line G O now represents the hydraulic gradient and works out in this example to 1 in 10

As the material the weir is built of is twice as heavy as water, if we make AC = AB the triangle ACO will represent the theoretical thickness of floor needed to balance the varying heads of water pressure

The ordinate CB represents the head at C and as this is over 16′ we need a thickness of floor at this point of 8′ at least

A cistern may be formed by building a cross wall, but it would need to be 4′ deep Can the floor be made safe without adding anything to the down stream floor? Certainly it can, by flattening the hydraulic gradient Make AB′ = AD = 6′. Join OB′ and produce the line OB′ to cut the full supply level at H. All we have now to do is to arrange to start the hydraulic gradient at H, and this can be done by adding an impervious upstream apron to J, or partly by an apron to K with piles as shown in the sketch It i infinitely better to do it in this way than with cross walls on the downstream floor, as each of these cross walls becomes a secondary fall causing further action

The hydraulic gradient could also be flattened by driving piles on the down stream side at O, but as this would send the zero of the gradient further down-stream, the static head on the floor would be increased, necessitating an increase of floor thickness which we wish to avoid.

For a weir with a vertical drop, in sand, I am entirely in agreement with the remarks of Sir Hanbury Brown, page 371 of Buckley's Irrigation pocket-book—

(1) That extension of the impermeable platform, up-stream of the drop wall, decreases the upward pressure on the floor below the drop wall, at the same time that it reduces the steepness of the hydraulic gradient and therefore the rate of flow of the percolation water.

(2) That extension of the impermeable platform down-stream, has the disadvantage of increasing the upward pressure on the floor below the drop wall, though the steepness of the hydraulic gradient is favourably affected in the same way as by an up-stream extension.

(3) That for these reasons a curtain wall is well placed if up-stream of the floor, but badly placed if down-stream, except as a precaution against cutting back and undermining of the floor.

(4) That it is a mistake to grout pitching on the drown-stream side of the floor, unless the pitching cannot otherwise be made strong enough to resist scour, it being assumed that the watertight floor below the drop wall, is made strong enough and wide enough to withstand the impact of falling water.

A careful perusal of Appendix VII in vol. II is strongly recommended.

CHAPTER VIII.

RIVER TRAINING WORKS.

1. **Object of Training Works**.—It is necessary for the Canal Engineer to study the questions connected with river training, because he is often compelled by the necessities of his works to interfere with the natural regimen of rivers, and it is therefore incumbent on him to maintain and restore or improve that condition, and also, because on account of his familiarity with the mechanics of water, he is necessarily consulted by other branches of the profession when questions connected with the management of these forces have to be dealt with.

As noticed in the preceding Chapters on Field work and Works, it is often impossible to select a perfectly satisfactory site for the construction of weirs, regulators, or drainage works, but an improvable site may be obtainable, *viz*, one that will suit the purpose intended after certain alterations in the course or position of the river have been carried out, and here one of the first duties of the canal officer is to design and put in operation the works necessary to attain this end.

2. **Works of Protection and Direction**.—Training works may be either Protective or Directive, or both. They may be required for merely temporary purposes, or as permanent guardians of the situation annually exposed to severe action or they may have to be placed in a position ready to meet an emergency when it occurs, and thus remain for years unaffected by any action from floods. It is essential, when designing training works, to consider very accurately the actual object which it is necessary to attain, and to lay down the lines of action required clearly and with care, remembering that the work to be done may last for years of steady application before complete success is attained.

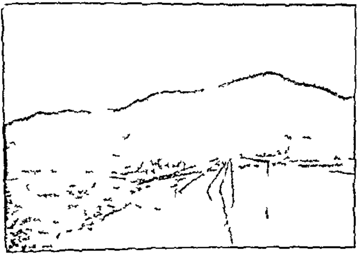
In no other class of work is the mind of the Engineer so liable to be diverted from the main to some subsidiary object. Experience often gives him great facility in controlling or diverting the vast powers of a large river in flood and over confident, he sometimes attempts to locally improve matters to a degree the river will not permit, the result being either a sudden change in an unexpected direction, wrecking the work of years, or an annual expenditure on maintenance wholly incompatible with the object originally aimed at.

3. **Application of force by moving water**.—A body of water moving in a channel, the bed and sides of which are hard enough to resist its

erosive action, will travel with greater velocity than will be engendered in a channel of the same slope and section of which the bed or sides can be eroded. This reduction of velocity in the latter case is due of course to part of the force which moves the body of water in the first case, being used up in the work of cutting and carrying the material of which the channel is formed. If the supply of water to the hard channel is limited, the increase in velocity will result in a reduction of depth and area of moving water section.

It is a common remark that silt-laden water has less erosive power than clear water; the reason for this is the same, the water carrying silt is expending part of its force in doing this work, and its power of eroding and carrying more silt is correspondingly lessened. There is undoubtedly a limit to the quantity of silt a given volume of water moving with a certain velocity can pick up and carry, and when water has thus laden itself, it cannot erode more, no matter how soft the material of the channel may be; but the slightest addition to the velocity will add to its power, and cause it to take up more, *if the force is applied in the proper direction* and the slightest reduction in velocity from any cause will at once induce a deposit. Thus, from apparently slight causes, often imperceptible to the closest observation, a body of water may be frequently changing its load of silt, and steadily, though by very slow degrees, completely altering the constitution or regimen of its channel.

The velocity of the water alone is not the gauge of its erosive power; just as is the case with forces applied by stiff material, so it is with water, the direction in which the force is applied influences the effect. Water sliding over a sloping foreshore will not erode in anything like the same degree as when it impinges on an abrupt cliff. This point will be at once understood if the effects of a sharp chisel applied to a soft wood surface at different angles is considered; if the angle of application is acute the edge of the chisel will slide over the surface of the wood without effect; if the angle is made obtuse, even a slight force will cause it to enter and cut away the wood. It is well known that a boulder lying on the sandy bed of a river will be buried by the floods; the reason for this is that the forces of the flowing flood water, sliding over the smooth sandy bed, when they meet the obstructing boulder are diverted by impinging on its hard surface to directions suitable for the erosion of the soft sand on which it lies, and this sand being removed the boulder gradually sinks. Exactly the same effect is produced on a large scale when a current of water is obstructed by any hard structure, such as a spur, groyne, or revetment; the



TEMPORARY HEAD BUNDS BHIMGODA GANGES RIVER

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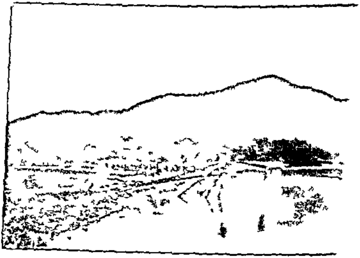

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Photo Mechl. Dept. [illegible]

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forces of the current striking it are diverted to directions useful for scour, and the soft material of the bed near the hard structure is removed. If the foundation or design of the hard structure is unsuitable it will be destroyed, and this result will be more quickly attained by the action of the current if it can succeed in isolating the structure and acting on all sides of it by cutting it off from the bank of the river to which it was originally attached.

The remarks made above will at once explain the reasons for the well known fact that a rocky cliff, or any hard structure of abrupt projection, on the banks of a sandy river, has a tendency to attract the deep channel of the river to its vicinity. The first effect on the hard structure may be slight, but if its form is not calculated to very gently divert the stream, scour will be induced by even slight currents which will in time cause a deep channel to be formed, and may eventually bring the main volume of the river on to the obstruction.

4. **Dead water.**—Water flowing in a channel may be confined to a certain course by the obstruction of dead waters, *viz.*, masses of still water, as well as by the hard or soft material of the bed and banks: and when such a mass of dead water cannot be bodily put into motion by the forces acting on it, it forms by far the most effectual resisting material, and it may indeed be said, that sometimes the true function of a groyne or spur is not of itself directly to oppose the current, but to hold up a great mass of dead water and thus control the river. A very slow motion in the mass of dead water thus held up is not objectionable, it may even be advantageous, as it may lead to the formation of a bed of hard clay on the bank of the river above the groyne from very slow deposition of fine silt. The dead water will of course not reduce the action on the nose of the groyne.

5. **Straightening channels.**—When a proposal to straighten any given length of a river, or to cut off a loop, is being considered, the Engineer must bear in mind that if the original material of the bed and banks remains unchanged, and the river gradient is not in any part artifically absorbed, the *channel will regain its original length* in some way or another. The natural length of any channel must evidently be that which will produce a velocity suitable to the material of which the channel is composed, viz., a velocity which will neither scour nor deposit silt. It is true these actions are constantly at work to a greater or less degree in almost every river, but this is due to either natural or artificial interferences with the condition of the channel, such as a rise or fall in

the volume, an alteration in the quantity of silt carried by the water, or floating *debris* getting attached to the bed and obstructing the current. In all these cases the forces at work are trying to balance themselves, interference at one point causing action at another, just in the same way as a delicate governor influences the speed of an engine, perfect uniformity is never attained, but the mean result is the correct speed.

This condition of velocity determining the dimensions of the channel is not confined to streams with easily eroded beds. The author was once directed to report on the floods of a hill torrent which caused great devastation; very extensive training works had been constructed without any good effect, the slope was like a hill side, and the bed composed of great boulders and shingle piled up apparently in inexplicable confusion. A very careful examination of the bed was made, the slopes and discharge areas being taken out at close intervals, and this showed that nature was not the least confused, every section being most accurately adapted to carry its proper flood volume. The training works then designed with the care necessary to preserve the natural regimen of the torrent proved effective.

It may, therefore, be accepted as an axiom that if a channel is straightened, and its length reduced by training works, unless the excess slope is absorbed, the stream will at once endeavour to lengthen the channel at some place or other above or below the straightened length, or in that length even if the protection is insufficient. The situation is well exemplified by measuring off the curvature of the river on a map with a piece of thin whalebone, between points some distance above and below the length to be operated on; if the ends of the whalebone be held on these points and a portion of it be straightened, the remainder will curve and the curves may take any shape or direction, but the length will remain the same.

The construction of a weir across a river bed or a raised bar of any nature, will absorb slope and allow of a certain amount of straightening without ill effects, but the Engineer should not fall into the error of trying to make the situation too perfect by attempting to improve a great length of river without good cause; it is incumbent on him to protect a certain length of river above and below his works, but the limits within which to train should be strictly defined by actual necessity.

6. **Cuts.**—It has been stated before that a river rarely re-occupies an old deserted channel of its own accord. An old channel as it is gradually deserted, slowly silts up and eventually gets lined with clay on a contour

down which flood spills can pass smoothly without causing erosion. A new cut will be quickly occupied by the stream, and eroded to the full dimensions required for the volume, if it has a greater slope than the portion of the old channel to be abandoned, has a good entrance, soil as loose as that of the old channel, and is not too long. The occupation of the new channel will take place even if the new cut is dug quite narrow at first, and the old channel left open, unless some blocking of the head of the new cut or other interference stops the erosion; if this occurs, there is great danger of the new cut rapidly silting up, and the stream again taking in a determined manner to the old channel.

There is, therefore, a strong probability of failure when a new cut is made, which is only slightly better situated as to slope and direction to the old channel it is intended to replace. The balance of advantage of both channels may be so even, that the slightest interference will silt up the new cut, which requires a decided advantage to enable the stream to scour it out. If it is a long cut, the sand scoured near the head is liable to be deposited lower down in the cut, and this process, if continued, will certainly close the channel. Indeed, it is very difficult, if not impossible, to scour out long cuts, no matter what advantage they have, unless the supply is artificially forced into them by partially or wholly blocking the head of the old channel.

The process of the stream abandoning an old and scouring a new channel is simple enough. We will suppose that the old channel was exactly suited to the volume it had to carry: now when a portion of this volume, however small, is abstracted by the new cut, the old channel must silt up in a degree to correspond to the reduction in volume. The sand scoured out of the new cut is deposited near the tail of the old channel, and this also slightly reduces the water surface slope and carrying capacity of the latter; this tends to force more water down the new cut. The process goes on until the old channel is abandoned in favour of the new cut or until the action is reversed by some interference.

Freshly deposited silt is much more easily eroded than old compact soil, and a very slight block to the scouring power in a new cut may quickly reverse the balance, when the river will return to its old course.

When a new cut is being occupied and the process is slow, the old channel will be nearly filled up with silt; when it is quick the old channel may remain open for a long time, unless special arrangements for warping up are made.

the volume, an alteration in the quantity of silt carried by the water, or floating *debris* getting attached to the bed and obstructing the current. In all these cases the forces at work are trying to balance themselves, interference at one point causing action at another, just in the same way as a delicate governor influences the speed of an engine, perfect uniformity is never attained, but the mean result is the correct speed.

This condition of velocity determining the dimensions of the channel is not confined to streams with easily eroded beds. The author was once directed to report on the floods of a hill torrent which caused great devastation; very extensive training works had been constructed without any good effect, the slope was like a hill side, and the bed composed of great boulders and shingle piled up apparently in inexplicable confusion. A very careful examination of the bed was made, the slopes and discharge areas being taken out at close intervals, and this showed that nature was not the least confused, every section being most accurately adapted to carry its proper flood volume. The training works then designed with the care necessary to preserve the natural regimen of the torrent proved effective.

It may, therefore, be accepted as an axiom that if a channel is straightened, and its length reduced by training works, unless the excess slope is absorbed, the stream will at once endeavour to lengthen the channel at some place or other above or below the straightened length, or in that length even if the protection is insufficient. The situation is well exemplified by measuring off the curvature of the river on a map with a piece of thin whalebone, between points some distance above and below the length to be operated on; if the ends of the whalebone be held on these points and a portion of it be straightened, the remainder will curve and the curves may take any shape or direction, but the length will remain the same.

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employed separately or combined as one work, according to the necessities *of the case, and a complete training work often includes all five methods* in its system

9 **Aprons**—A subsiding apron is generally constructed of loose stone boulders or other heavy hard material, but may also be made as a brushwood mattress loaded with hard material, when the latter is difficult to obtain The apron is laid horizontally on the river bank it is designed to protect of a length width and thickness corresponding to the anticipated dimensions of the scour The action of the flood current will remove the sand from under the apron causing it to assume an inclined position sloping from the top edge of the bank towards the river bed, when being in a favourable position to resist the erosive forces of the current, it will stop further action on the bank vide *Fig* 99 *Plate* XX

It will be noticed that the first effect of the apron is to attract action and *to deepen the river bed after the action has lasted some time the* new position of the apron stops the action on the bank, but the deepening of bed will go on until it has reached the possible maximum This depth is a moot point Forty feet for large rivers is accepted as a limit by many Engineers, but this has been exceeded in certain cases when the river was compelled to alter its position by the application of very powerful forces.

It is not safe to use aprons on a large scale unprotected by other training methods the river will be almost certain to get behind and turn the position into an island with the most disastrous results When it is desirable to narrow up and deepen the channel of a river, aprons, combined with powerful groynes and embankments, are safe and suitable agencies to employ On the banks of rivers with very powerful currents the material of aprons is sometimes confined by nets of wire rope to prevent disintegration

10 —**Permeable Spurs** —There are many forms of permeable obstructions such as *Tree, Pile* and *Fascine spurs Brownlow weeds* and *Mattresses* All these act by checking the velocity of the current in a greater or less degree according to their nature and by partially diverting its direction The check to velocity induces deposits generally below and about the spurs which are usually buried in the deposits they form when the operations are perfectly successful This however, is rarely the case, and however attractive it may appear to influence a great river by such simple temporary methods the result will generally be found unsatisfactory, both in the immediate result and for the reasons previously

noticed. It is necessary with these great sand bed rivers not only to put them into the desired positions, but to maintain them, and for this permanent works are evidently required.

The selection of any particular form of temporary spur will depend on the nature of the bed and the effect it is desired to produce. It would be absurd to put piles into the bed of a river liable to 40 feet scour, or trees on a boulder torrent capable of sweeping away the section of a forest; it is also very necessary to select the means to be used, in conformity with the materials that can be procured economically in the locality of the works.

11. **Tree Spurs.**—The following abstract of a note on Tree Spurs by Mr P. Denehy, a well-known expert in training works, describes the construction and uses of this method of training rivers:—

"It is a difficult matter to make a general estimate for tree spurs, as much depends on the locality from which the trees have to be brought, carriage being a very heavy item, and a great deal depends on the kind of tree spur to be made. The general idea of a tree spur is a single line of small trees across the stream, but this kind of spur is never of much use. The river is generally in a worse condition after the close of the operations than it was before they were begun, and to be of real value, the trees should be sufficiently close to effectually check the current, and to divert at least 75 per cent. of the volume A tree spur of this kind is very expensive and is seldom made. The first thing to do is to lay out the alignment which should form an angle of 30° with the stream. The line for the anchors should be laid out and not that for the trees; this line should be in prolongation of the centre of the channel into which it is desired to divert the stream; it should be marked at every 100 feet either with a pole or a buoy. When this has been done, both flanks of river should be protected with brushwood or fascines, weighted down with hard material—this is necessary to prevent the river outflanking the spur.

"The next operation is to get the trees into position. An anchor, a common one such as that used to anchor country boats, with the cable, a rope 75 feet long and 9 inches circumference attached to it, (*see Fig.* 100, *Plate* XX), should be put on board a boat with a rough upper deck; some six to eight small bushy trees or branches should be lashed on to the other end of the cable, the lashings being 1½ to 2 inches thick, and long enough to allow of the trees being at a distance of a couple of feet from the cable when lashed on. A fair-sized country boat will take three

anchors with cables and trees complete on board The boat should be taken into mid stream and anchored in such a position that the cable anchors may be thrown overboard in the proper alignment The current will float the trees into the proper position, which should be 60 to 70 feet down stream of the anchors If the anchor drags, some trees should be removed, if it holds, more may be added. The number of trees which can be put on to one anchor depends on the current and the density of the trees, and can only be ascertained by actual test in each instance, but it is always better to have too few than too many as additional trees can always be lashed on to those already in the water when the latter get partially buried in the silt When the first anchor is properly in position the others can be put in about 10 feet apart so that the trees may meet and overlap a little

"The first boat load of trees will form an island mid-stream, dividing the channel into two streams, the following boat loads should be placed mid way in these streams, and so on, constantly sub-dividing the channel into minor streams until the several groups of trees meet and form one unbroken line right across the channel to be diverted.

"If any of the trees sink below water level, or any gap be noticed in the line, new trees or bundles of brushwood should be lashed on to the old trees right and left on the gap It is important to see that there is no undue velocity in any part of the spur, as soon as this is detected additional material should be fastened on, or if a serious gap is formed a new anchor and cable may be put in.

"If the line is maintained as described, with a falling river the whole stream should be diverted in a month The object of placing the trees in separate groups is to interfere with the river bed as little as possible and to avoid creating excessive scour at any particular point If a tree spur is run out from one flank, it will gradually increase the velocity at the head, and before the spur is 100 feet long scour will set in, and the probabilities are that there will be a depth of 20 feet of water where there was only 5 feet at starting

"It is much easier to divert a broad shallow channel if properly worked than a narrrow deep one

"Once a tree spur is started the work should be rushed ahead with all speed, especially as the gaps become narrow One boat should be able to do 100 feet of tree spur *per diem* provided all material is ready, the men sufficient in number, well trained and properly directed Twenty men and a ganger form the crew of a boat

"All cables and ropes should be of the best local material available, well twisted by machine until quite hard.

"It will be seen that an efficient tree spur is a very expensive and troublesome undertaking; it is not recommended for general use, but there may occur cases where no other method can be applied. The operation requires the supervision of competent authority, as from the nature of the work it is practically impossible to measure up or check the expenditure on labour or materials."

12. **Pile and Fascine Spurs.**—Pile spurs generally consist of two or three rows of piles, the intervals being filled with brushwood or fascines, which stand well against the stream, and by checking it and causing a deposit of silt, gradually effect the purpose required. Pile spurs are suitable for channels which are not liable to very deep scour, or which have a clay or firm substratum. It is calculated that such a spur will defend seven times its own perpendicular length from the shore, *viz.*, four times its length below and three times above, but this statement must be received with caution. For mere economy of construction, therefore, the more perpendicular such spurs are run out from the bank the better; but when the velocity is great and the spur is long, if placed perpendicular to the direction of the current, the piles will not stand, and if placed inclined to the direction of the stream they divert its direction and scour is induced all along the face of the spur. If the object is merely to protect the shore, it is better to use a greater number of short spurs than a small number of long ones; and the system should be so arranged that the next spur is put in when the one above it ceases to act.

If the object, however, is to deflect the current to a considerable distance from the shore, long spurs inclined to the direction of the stream may be used. The tops of the piles should in all cases be well above the surface of the water, so that the surface as well as the under-velocity may be checked.

When a pile spur acts properly it should collect silt in its vicinity, and the filtering of the silt-laden flood through the fascines has some tendency to cause clay deposit.

As a general rule pile spurs are not used when more satisfactory material is locally available, but at the time of writing, a great system of training works is being constructed at Dera Ghazi Khan, in which, immense piles are being largely used. The results of these works will afford interesting information.

13. **Brownlow Weeds.**—The object of this floating spur is to imitate the action of weeds in flowing water, and by checking its velocity to bring

about the deposit of silt in any channel which it is desired to close The advantages of the system are, that the flow of the water is only checked and not totally obstructed, that all violent action and scour along the face and at the toe of the spur are thereby avoided, that as silt is deposited in the channel, the hydraulic mean depth and velocity of the stream are decreased, so that the work helps itself on that the change effected is gradual, giving the water time to scour itself out a new channel, whilst the old one is being closed and, finally, that the river is made to do the work of filling up its own channel, which, if merely closed off by a solid embankment, would always remain unfilled and a source of danger

The construction is very simple. A stout hawser, of a length equal to three or four times the depth of the stream, is strongly fastened to an anchor at one end, and to a buoy at the other, and to it are attached branches and brushwood, or small trees may be lashed to it by their butts. (*See Fig* 101 *Plate XX*)

The anchors may consist of concrete blocks, or of crates, or strong nets full of kankar and brickbats, and should be heavy enough when immersed to resist the drag of current on the streamer. They can be sunk in line with fair accuracy from a derrick in the bows of a boat, should the water be too deep to admit of their being filled and closed when in place. (*See Fig.* 102, *Plate* XX),

The buoys can be omitted if the current be very strong and likely to carry away the streamer The latter would then lie along the bottom, powerfully checking the bottom velocity, and rapidly reducing the depth of the channel by the deposit of silt. Where buoys are used, it might be advantageous to keep each adjacent pair apart from each other, by light rigid connecting rods BC, DF, so as to prevent the streamers from getting twisted together.

The streamers should be bushed more heavily at the bottom than at the top, in order to prevent under-cutting, and be placed closer together at the heel than at the toe of the spur The portion of bank AE should be protected with special care, so as to guard against the water cutting round the heel, or into the bank below the spur. Rough pitching of a sloping bank, or hanging trees, head downwards, from the crest of a vertical bank will ensure its protection.

The alignment of the spur can either be perpendicular, or at an inclination, to the axis of the current, for the water passing freely through the spur, no violent set is imparted to the stream and no scour takes place

along the up-stream face or at the toe. On the Sutlej, the streamers were successfully used in lines parallel to the bank, and a foreshore may thus be created to a perpendicular bank that is being undermined.

The chance of success of Brownlow weeds as a training method depends a good deal or the balance of attraction down the two channels, one of which it is desired to divert or close the stream from. If this is very strongly in favour of the stream to be diverted or closed, the first effect at all events of the weeds will be to reduce the waterway and increase the velocity, and thereby the scouring power of the current. If the anchors and weeds cannot be carried away they will be sunk or buried, and may to some extent thus protect the bed. Constant renewals of the weeds and improvements to the new outlet for the flood may, in time, produce success, but at great expense, and this method of training or diversion of floods volumes is most suitable for channels which only require moderate impediments to divert the current from them.

14. **Mattress Spurs.**—In localities where hard material is difficult to obtain and brushwood plentiful, mattress spurs and aprons will be found useful training methods. The mattress can be used as a spur to direct the current, as a spur or an apron to protect the bank, or as a permeable embankment to close a channel. The branches obtained by trimming trees or tough jungle growing on the river banks are used for making mattresses; willow is probably the best material.

The mattress consists of brushwood contained between two layers of fascines, and is constructed as follows*:—(*See Fig.* 103, *Plate* XX):—

Lay a row of fascines of the required width, each fascine being of the full length of the mattress. Then drive stakes into each fascine at intervals of 2 feet, and to each stake tie one end of a rope, the other end being attached to the fascine. On the bed of fascines thus formed lay brushwood 3 to 5 feet thick, and on top lay another layer of rows of fascines similar to the lower rows but at right angles to them. In this layer the length of each fascine will be the full *width* of the mattress.

By pulling up the stakes that were driven into the lower layer, the ends of the ropes attached to them can be brought to the surface and bound round the upper fascines, thus compressing the brushwood and compacting the whole mass.

The mattress thus formed can be floated to position by boats, and loaded down with stones or heavy material, or if the conditions are favourable, it may be made up and loaded on the site it is intended to occupy.

* Extract from note by the late Major R. P. Tickell, R.E.

Mattresses of considerable dimensions can be used with advantage from 30 to 50 feet wide and several hundred feet in length One of the great advantages of the mattress is its flexibility which enables it to adapt itself to the inequalities of the bed on which it is laid and also to assume a position favourable to checking scour (*See Fig* 104 *Plate* XX)

Thus if there is scour along the toe at A the mattress AB will assume the position AaB and effectually stop the action

Brushwood is a perishable material but as it rots its place is taken by clay sand and drift etc Mattresses have a tendency to cause clay deposits in their vicinity by filtering out the sand above and keeping the water below still

When it is not possible to obtain heavy material for loading at a reasonable cost bags filled with earth and bound to each other can be used In a recorded case a flood came down on a mattress which was not only unloaded but even unprovided with the upper fascine layer yet the mattress stood threw up a heavy silt deposit and diverted the flood This has led to a number of spurs being made of unloaded mattresses which have stood well but it would be unsafe to assume that unloaded mattresses can as a rule be depended on

When first using mattresses there is a temptation to try and assist them by using piles along their edges driving stakes into them etc This must be resisted as it deprives them of their great advantage viz flexibility

15 Impermeable Groynes or Spurs —These works can be built of an infinite variety of designs from a simple sand spur supposed to effect its object as it is being rapidly washed away by the current to a massive groyne costing lakhs of rupees The most ordinary forms used are—the *sand spur* obstructing a side channel it is desired to close with its head generally ending on an islet or sandy patch in the river bed the *dry stone* or *boulder spur* the *crate* or *box spur*, the *masonry* or *built, spur* and the hearted *groyne*

The selection of the particular form to use in any case must depend on the importance of the object to be attained the material available and the nature of the river

The action of a spur will be greatly influenced by its direction, thus a perpendicular spur will hold water up above it (this held up water is the real obstruction) and cause a reflex action below, which if not counteracted may eventually destroy the spur This reflex action is due to the

flood water trying to fill up the low level below caused by the obstruction of the spur. (*See Fig.* 105 *Plate* XX).

An impermeable spur, *oblique to the current*, as it cannot hold up water, will be exposed to severe scour in the direction of its length, where it is least able to withstand it. An oblique spur will direct the current, but will not protect the bank above. (*See Fig.* 106, *Pate XX.*)

An impermeable spur, acute to the direction of the current, will hold up water above itself, (*see Fig.* 107; *Plate* XX), and not cause such marked reflex action as a perpendicular spur; but the extra expense of construction will hardly compensate for this advantage, as the reflex currents can be counteracted by minor spurs projecting from the lower face of the perpendicular spurs, and the action on the head of the acute spur will be severe and complicated.

16. Sand Spurs.—Sand or earthen spurs unprovided with heads of hard material, though of little use as a permanent protection, may often be employed with useful effect in preliminary or subsidiary operations. The dry boulder spur is used in a similar manner in rivers and torrents near the hills where the velocity is great.

When boulders alone will not stand, crates of various forms made up of rough round timber are used to hold a number of boulders together, so as to provide more weight than the flood current can move, or the loose boulder spur may be covered with a net-work of wire rope, which has the same effect, and is more flexible.

Built masonry spurs are only possible when the foundation is either sound and not liable to erosion in the first instance, or has been made so by exposing box spurs to the action of the current until they are settled and compacted, when they can be built up with mortar into the form found most suitable for permanently resisting the action of the river. In some cases a spur is built up of large artificial blocks of concrete made specially for this purpose.

In most cases a revetment (*see* para. 23, Chapter VI) will be found a more economial and better protection to a river bank where there is action from high velocities, than a series of small spurs, which latter, though cheap to construct at first, require constant attention and repairs as long as the river acts on them.

17. Permanent Groynes.—A permanent groyne is a sand, earth, or stone embankment jutting out into the stream, with its head constructed of hard material so designed as to protect itself and the embankment from destructive action.

The training of a large river may be carried out by means of a series of groynes connected by marginal embankments, or by two powerful works one on each bank of the river. The employment of two powerful works only practically necessitates the excessive local deepening of the river bed, and is therefore, more suitable for bridges with deep well piers, than for weirs over which it is desirable to carry the volume of the flood in as smooth and even a manner as possible, and where excessive scour would certainly have a most injurious effect.

18 **Deep River training**—When only two groynes are employed, the railway embankments and bridge abutments practically form part of the groynes, and the deepening of the river bed in the vicinity of, and under the bridge, is purposely designed in order that the floods may have the greatest possible inducement to occupy the bridged portion of the river Many Indian rivers crossed by railways have channels of great width over which the flood volume wanders occupying sometimes one portion, and sometimes another but never the whole The area of bridge opening allowed for the flood volume in the portion of the channel selected as most favourable is only that carefully calculated when scoured out to 40 feet below normal bed as sufficient for the maximum flood, and it will be easily understood that very powerful training works are necessary to control the immense forces of a great river in a masterful fashion under such conditions.

The inception of this system of management of rivers for railway purposes, from which great efficiency and economy have resulted is due to Mr J R Bell, and the system of training is called the Bell's bund system The design of his groynes is practically the same as the canal training works at Okhla near Delhi The latest, and probably the most powerful works of this nature ever constructed are those for the training of the Ganges river at the Garhmuktesar bridge of the Oudh and Rohilkhand Railway The plan and section of one of the groynes and a sketch of the site, are given in *Plates* XX and XXI, and the following extract from a note by Mr Johns the Engineer in charge, will give a general idea of the scope of the work —

"The protection works are two simple parallel stone pitched bunds running at right angles to the abutments, and with plain straight noses at the ends The land sides of the bunds are sodded or lightly pitched according to circumstances It will be observed that whereas the western protection is 22 chains long up stream and 5 chains down stream, the Eastern only extends 15 chains up stream and 5 down The reason for this is that a further extension would have narrowed the Eastern channel excessively with the probable result of a breach in the training works if the river came down in high flood before the island above had time to cut away On the other hand it was feared that so short a

length of bund as 1,500 feet might not protect the railway in rear from attack as the bank projected some 3,000 feet into the old river bed. Actually the bund at its present length has been found to give ample protection, so the idea of extending it (*pari passu* as the island cut) till it equalled the West bund has been abandoned. The longer of the bunds is a little shorter than Mr. Bell's standard, which fixes the length of bund as a little greater than the length of bridge.

"Another difference from Mr. Bell's type, and I think an improvement, is that the noses are straight instead of rounded.

"The sections of the training works were based on those at Narora,* but inasmuch as there was no *point d'appui* on which to rest the up-streams ends of the bunds, and as both were liable to attack according to whichever branch of the river predominated, the amount of pitching material was practically doubled, i.e., 4 feet on slopes 8′ X 25′ on the berm, and the noses solid.

"There are about 30 lakhs of stones in the bund and 80 lakhs of earthwork, besides 10 lakhs of stone in reserve. The results after one monsoon are highly satisfactory; not a stone has been shifted, even at the nose of the East bund where the velocity was tremendous: while in high flood the river ran through the bridge like a canal, without any swirls or currents at the edges, though 50 feet off there was 40 feet of water. This I attribute entirely to straightness and evenness of line. It may no doubt be said that too much material has been used; the fault, if it exists, is on the right side; by using too little material one runs the risk of losing all. and repairs are certain to be heavy, whereas by using too much one loses little or nothing and for every reason it is desirable to have a good factor of safety in works of this kind.

"The pitching material was 2,200,000 cubic feet of stone from Delhi and 1,800,000 cubic feet of block kankar, the former is the heaviest, but the latter binds better, so there is little to choose between the two. The specification for the minimum weight of each stone was 80 lbs., with 15 per cent. of smaller material. The stone was hand laid to a true surface throughout.

"The total cost of the work will be about 6½ lakhs (£43,333). Construction was begun in December, and finished in May, about 170 wagons coming in daily when things were in full swing."

19. Great Weir Training Works.—The system of protecting a great weir by a series of groynes will be best understood by the description of successful operations of this nature, and the following extracts from a note by Mr. P. Denehy gives many interesting details :—

"The writer had to train the Jumna river at Okhla and the Ganges river at Narora; the former for a length of about 10 miles, i.e., 7 miles above the weir and some 3 miles below it, and the latter for 5½ miles above the weir and 16 miles below it. The works were started at Okhla in 1881 or 1882, long before the Railway Engineers realized the importance of the subject. Both the systems (Okhla and Narora) are practically the same, and consist of a marginal bund of earthwork running parallel to the river, and from half to one mile distant from it; from this bund spurs or groynes are thrown out at right angles to the axis of the stream, their heads consisting of rubble stone or block kankar. The length of any one groyne will depend on the distance from the groyne above or below it, and with groynes at intervals of half a mile, their lengths should not be less than half

*The Training Works at the Head of the Lower Ganges Canal, designed by Mr. Denehy.

a mile, the river will then cut or loop in a furlong or so behind the groyne head, thus leaving 3 furlongs between the river and the marginal bund or other work to be protected.

"For obvious reasons all the groyne heads should, if possible, be in a straight line, as they then assist each other, and they also bring the river straight on to the weir, and there is much less action on the groynes, as it is the sinuous course of a river that causes erosion, but for very great lengths this is not practicable, and it is necessary to provide for curves in the system, and in such cases the river should be divided into straight runs of not less than 4 miles, (the longer the better), no curves of any great length being permitted, for though they look quite the proper thing on paper, long curves induce the river to scour along the concave side, and at the end of the curve they cause to it impinge with great force on to the opposite bank With proper care and forethought it should be possible to arrange for a straight run of river for at least 5 or 6 miles above the weir, the initial expense may be greater than for a curving approach, but it is economy in the long-run, as it reduces the annual expense on repairs and maintenance, and it ensures the safety of the works which have to be protected It also ensures the safety of the groynes themselves

"The number of groynes in both the rivers mentioned above aggregates 60, *i e*, 16 on the Jumna and 44 on the Ganges, and though they have now been in existence for nearly 20 years none of them have been out flanked or carried away Although the general principle of the systems on both rivers is the same, considerable improvements in the detail of the groyne heads at Narora have been carried out These improvements suggested themselves from time to time, and though they perhaps involved some extra expense in initial cost, they have resulted in a great reduction of annual outlay on repairs and maintenance which, after all, on works of a semi permanent nature, is always the most important consideration

" As the Narora training works are the most important, and are of the improved pattern, it may be as well to describe them in detail *Plates* XXIII to XXVII will show the condition of the Ganges river before being trained, the various types of groynes tested, and the action of the currents on them

"The Narora Weir with scouring sluices is 4,200 feet long, The crest of the weir is 10 feet above the normal low water level of the river, and it is this raising of the bed of the river which necessitates the long line of training works above the weir and permits of a certain amount of straightening by reducing the effective bed slope, The canal takes out of the right bank of the river where the level of the country is some 50 feet above high flood level, and to avoid the deep excavation which for a canal 212 feet bed width would have been prohibitive, it was decided to run the canal along the *khadir* or valley of the river, and about half to a mile distant from it, for some 16 or 18 miles, until it reached a position where it could enter the high land in moderate excavation, It was to protect the canal from the erosion of the river that the long line of training works below the weir was designed, and to prevent the floods which are raised some 6 or 7 feet by the weir, from flowing on to the low land on the left bank above it, it was necessary to construct an embankment from the weir, up to the Oudh and Rohilkhand Railway embankment at Rajghat, a distance of some 5½ miles this embankment is known as the left marginal bund It was constructed at a distance of about half to one mile away from the main stream of the river The distance between the high bank on the right and the marginal bund on the left bank is about 1½ miles, through which breadth, before the construction of the training works, the river meandered from side to side, at times

threatening the destruction of the marginal bund; and as the valley was much too wide, the velocity of the river being checked by the weir, large islands immediately above it were formed by deposits, which masked three-quarters of the weir.

"Below the weir the force of the river was drawn to the right flank chiefly through the action of the weir sluices, which have to be worked almost continuously in the floods, to keep the channel above the canal head open, and the canal itself free from silt. As these sluices are capable of discharging some 40,000 cusecs, and the normal discharge of the river during floods is not more than 100,000 or 120,000 cusecs, the continual discharge of 40,000 cusecs through a narrow channel (the weir sluices are only about 400 feet long with a waterway of 265 feet, while the weir has 3,800 feet clear waterway) induced a very deep channel on the right flank, and erosion of the land between the river and the canal set in from the date the canal was opened in 1877.

"In 1887 less than two furlongs of land remained between the river and canal at various points in the first 12 miles below weir, and the Ganges has been known to cut through a mile in 24 hours, so the position of the canal at that time was very precarious. Various methods of training the river above and below the weir were resorted to in the ten years above noted They were mostly of a temporary nature, such as tree spurs and earthen bunds across spill channels, or projecting into the river; but an attempt at permanent training by means of groynes with the old horseshoe-shaped heads, of kankar in cribs or crates (*see Plate* XXVIII) was made above the weir; however, all these methods lacked permanence, and there was no finality to the work, so that the expenditure went on increasing gradually from year to year, until in 1887, the total annual expenditure had risen to nearly two lakhs, and the worst of it was that the state of the river after each year's operations was worse than its condition in the preceding year; the aggregate expenses for the ten years amounted to 10 lakhs. The horse-shoe groynes above the weir failed, because, though there was a great quantity of material in the groyne heads, it was not placed so as to protect the up or down-stream faces of the embankment, and the force of the river struck against the head (which had nearly vertical sides) creating swirls and eddies which scoured out a very deep hole at its base: this hole extended back to the earthwork embankment, and the whole structure either collapsed into the deep hole, or the embankment got breached behind the head.

"The whole five groynes of this type were carried away in 24 hours during the high floods of 1880; since that date to 1887 tree spurs were resorted to, but these owing to their perishable nature had no permanent effect.

"In 1887 the Okhla system of training works was introduced below the weir and 28 groynes of the Okhla pattern, with certain improvements and modifications, were constructed in the course of five or six years; also two groynes of the new type. In 1898 it was decided to train the river above the weir similarly, but here the new type (*see Plate* XXV) was introduced, and in order to bring the river straight on to the weir and get a channel free from islands and all obstructions, it was decided to have groynes at both flanks of the river, each pair of groynes facing each other, the distance between their heads being 3,000 feet, *viz.*, the normal width of the river Those groynes acted admirably, and there is now a clear straight channel between the Oudh and Rohilkhand Railway Bridge and Narora, a distance of about 5½ miles.

"The expense incurred on these works from 1887 to 1900 including annual repairs and maintenance was 10 lakhs of rupees, or just what was spent in the 10 preceding years on the temporary expedients already referred to and since the whole system was completed the annual expenditure has been reduced to something like Rs 30,000, and this no doubt will be considerably reduced as time goes on, and when the groyne heads have finally settled down to the deepest scour which the river is liable to The difference, therefore, in temporary and permanent river training works over a period of some 23 years at Narora is that the latter only cost 10 lakhs in 13 years, with a permanent reduction at the end of that period to Rs 30 000 annually, and the former cost 10 lakhs in 10 years, with an annual expenditure at the end of that period of 2 lakhs Moreover, there are now 44 groynes standing in perfect order and repair whereas in 1887 there was not a semblance of the temporary works left experience therefore shows that temporary river training works should only be resorted to as a very temporary measure and in case of great emergency The advantage of the new type of groyne introduced above the Narora Weir is that, having its head lengthened out, it affords better protection to the up and down stream faces of the embankment, and running parallel to the river it creates less action, and therefore the annual repairs and maintenance are greatly reduced The double headed groyne at Okhla and below the Narora Weir stands very well, but it does not extend sufficiently up stream and the river cuts in behind it It affords no protection at all down stream and the action caused by the portion which projects into the river is tremendous, and cours away the berm from the toe of the slopes, and this goes on year after year for at least five or six years, whereas the heavy action and repairs to the new type practically ceases after three years The initial cost of each type is practically the same say about Rs. 15,000 but the annual expense on repairs and maintenance may be taken as follows —

	Old type	New type	Remarks
	Rs	Rs	
1st	5 000	3 000	
2nd .	3 000	2,000	
3rd . . .	2 000	1,500	
4th	1 500	3 500	And lasts seven years
5th	1 000		
	2 500	.	" , five "
Total .	15,000	10,000	

so that the cost of the old type after 10 years amounts to about Rs 30 000, and the new type after the same period, would be about Rs 25,000 and the latter has the advantage of offering a better protection to the embankment as already described

"In addition to the above, it is most necessary to provide a reserve of at least 50,000 cubic feet of material on both types. This would bring the expenditure up to Rs 35 000 per groyne for the old type and Rs 30,000 for the new type If the writer had to carry out a system of training works similar to those at Narora again, he is quite convinced that it would be possible to reduce the expenditure by another Rs 5,000 per groyne by increasing the thickness of berms from 6 to 8 feet and the width from 20 to 25 feet, this would add another Rs 4,000 to initial cost, but the berm need not then be repaired until

the width was reduced by erosion to about 10 feet, and in ordinary cases settlements would cease at this point, and it would only be necessary to maintain them to this width, the cost of which would not be greater than Rs. 5,000 for 10 years* The advantage of massive groynes is proved by the splendid result on the Garhmuktesar bridge (see para. 18).

"When designing groyne training works it is necessary to pay attention to the following points:—

(i) The result of a series of groynes at half-mile intervals is to straighten the river out and to cause silt to deposit in between them, but there is always a loop cut out above and below each groyne: the greatest depth of this loop observed in 20 years is 660 feet, or exactly one-fourth of the distance between the groynes.

(ii) The whole length of a groyne should if possible be in a straight line.†

(iii) The groyne heads should be parallel to the river, and at right angles to their embankments, the whole groyne being again at right angles to the marginal bund, or other work, which has to be protected.

(iv) The faces of groyne heads should be perfectly free from any irregularities or projections, such as trees, cribs or small spurs; all such projections create swirls and eddies which tend to undermine the groyne heads above and below them.

(v) All diversions of rivers and spill channels should be made inside or at the land side of the groyne head, as if they are put into the river they offer obstructions and tend to injure the structure.

(vi) If the head of a groyne has to be built where there is a deep scour, do not alter the position of the groyne to avoid expense of filling up the hole, as a great deal depends on the alignment of the groynes; and do not fill up the hole with solid material, which is a useless expense, and in fact is injurious to the structur as it would cause irregularities in the action of the currents. The best thing is to fill up with sand to low water level and build the groyne head on top of the made sand platform. Should the velocity at site of head be too great to admit of sand filling, it may be necessary to make a cofferdam with brushwood, or other perishable material, and if rubble or broken bricks has to be resorted to, care should be taken that no solid material projects outside the groyne head.

(vii) The proper method of closing or diverting a channel which may happen to lie inside the alignment of a proposed groyne head is to first raise an embankment at both sides of the channel, so as to prevent the water spilling over the banks when the channel is being closed; having thus secured both the flanks from erosion, collect a sufficient quantity of material close at hand to close the channel in as short a time as possible. Have sufficient boats to form a gangway right across the channel—this material should be on both flanks. A crowd of men should then be put on to place the material which should be laid right across the full width of the channel in 2-feet layers. If this is done

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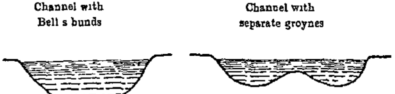
*The amounts quoted in this note can only be read as representing the relative cost of each type of construction. The actual cost at any particular locality will depend on the facilities for supply of material and labour.

†The somewhat erratic alignment of several of the groyne embankments at Narora, is due to old existing banks having been accepted as the base of some of the new heads when the temporary training expedients were abandoned.

there will be l ttle or no scour, as the bed gets gradually paved, any material such as brickbats will do for the lower portion of this kind of work, but as the bund reaches near the surface larger material must be used, as the increased velocity due to the reduction of area will carry away small material

"Another simple method of closing or warping up a side channel A (*see Fig* 108, *Plate* XX) is to dig a reverse cut C to the main river, and make a sand bund B across the side channel the reduced velocity in A will rapidly warp up the channel

20 **Length of Training Works**—It must not be supposed that all weirs will require the immense length of training works built at Narora. here the great length of canal and marginal bund exposed to the fluvial action necessitated these costly extensions A reference to paragraph 11, Chapter IV and paragraph 16, Chapter VI will show the necessity for great care in aligning the head length of canal and the flood spill embankment With works aligned as there shown necessary, it is probable that the permanent training groynes for a weir over a large river could be confined to a total length of five or six miles A little consideration will show that there is no real difference in principle between the Narora groyne system and Bell's bunds as built at Garhmuk tesar, the latter being a single pair of immensely powerful groynes In action, however, there is the important difference that with Bell s bunds the heads of the groynes are approached near enough to each other to scour the river bed to a great depth, while at Narora, as this could not be permitted for a weir, the flood currents fluctuate from side to side occupying deep beds at the sides of the channel with moving deposits in the centre.



The Narora system is, therefore, to a certain extent unstable as compared with Bell's bunds, and it is possible that narrow deep channels at the entrance and exit of the training system with the intermediate series of groynes gradually widening out as they approached the weir would tend to a more constant and even river bed.

One point is of the highest importance in training operations, *viz*, the determination of the true length of channel really required by the river between any two given points, it is doubtful if this point has ever received the attention it deserves, yet on it mainly depends the permanence of the training system

21. Inundation Embankments.*—The tendency of Indian rivers to shift their course and raise their beds by the deposit of silt has already been remarked upon: one effect of this tendency is to cause severe inundations during the rainy season. Nearly all the rivers of the Punjab and Upper India, in general, flood their banks for a certain breadth on each side throughout a considerable portion of their course, these inundations gradually increasing as the river approaches the sea, where it terminates in an immense delta—which, during the rains, is little better than a vast swamp.

Now so long as these partial inundations are confined within reasonable limits, little harm and much good result from them. They do not, it is true, tend to the healthiness of a district, and they prevent any autumn crop being sown on the inundated land; but the silt deposited by the water tends so to fertilize the land, that, on the subsidence of the inundation in the cold weather, the richest crops are produced with scarcely any trouble. In such parts of the country, it is customary for the cultivators to construct temporary villages, which are abandoned when the *rabi* or spring crop has been reaped: or such villages as are permanently inhabited are built upon natural or artificial mounds, and if necessary, defended by embankments.

The autumn crops which lie along the edge of the inundation are also defended by bunds which often extend for miles in length; these bunds are of no great height or solidity, as they are not built where the water is deep, and are merely meant to save the crops.

But such inundations, from local causes, often attain to great force, and sweeping over the low ground, may extend through the heart of a district with a breadth of many miles and a depth of several feet. Houses, villages, and crops are swept away—cattle and even human beings destroyed. Moreover, the water no longer flowing with a gentle and scarcely perceptible current, acquires great velocity in its course through the low land and having no time to deposit its silt, impoverishes instead of nourishing the soil. An Engineer is often called upon to provide a remedy for such a state of things, and there is no work that demands more patience and skill, and none more anxious or interesting in its results.

Thus it will be seen there may be two classes of embankments designed to provide for two different states of things, viz., (1), long continuous

* Extracted from "Roorkee Treatise on Civil Engineering," Section Irrigation Works edition of 1877.

lines of embankment to check the spread of lateral inundations, and confine the river within certain limits, or (2) a comparatively short piece of embankment thrown up to shut out a merely local inundation

The science of embanking, if it may be so called, is still in its infancy and very diverse are the opinions of Engineers on the subject It is contended by the opponents of river embanking in general that such embankments, by restricting the bed of the river within certain bounds cause such a rapid elevation of the bed from the free deposit of silt, that the waters of the river are year by year raised to a much higher level, the embankments have therefore to be raised and strengthened regularly, so that at last the bed of the river may be raised considerably above the level of the surrounding country, as is the case with the Po in Italy, and the Mississippi at New Orleans— thus whenever a breach may occur, the inundation is infinitely more destructive than any number of inundations when the river is allowed to take its own course unchecked

On the other hand it is contended, that by confining the river between embankments, the velocity of the current is increased, and thus the amount of silt deposited is lessened,—that the improvements of the river thus effected for navigable purposes, together with the great area of land annually saved from inundation, more than compensate for the loss caused by an occasional breach of the embankment,—that the evils of the present system of embanking arise from the want of method by which it has been characterized, and by no means involve the general principle —and that if a certain amount of space be given for the river to expand in on both sides of the cold weather channel, there is nothing to be feared with ordinary precautions

In America, the question of embanking or non-embanking has been practically settled by the occupiers of the land on both sides of the Mississippi, where, as fast as the ground has been taken up and cleared, bunds of *levees* (as they are there termed), have been thrown up as a defence against the encroachments of the river The maintenance of these levees is being gradually brought under the control of the States in which they are situated, and Civil Engineers are now generally employed to lay them out, and construct them on the best principles *

* The Student may consult Hewson on "Levees,' and Ellett 'On the Mississippi and Ohio Rivers, also the very able report which has already been referred to "On the Physics and Hydraulics of the Mississippi River."

In important cases levees should be made double, the two being separated by an interval of perhaps 100 yards and connected at intervals by cross bunds. The advantage of this method would be clearly the isolation of any breach in the first embankment; and by gently admitting the water through temporary sluices into the interval, there would probably be so large a deposit of silt, that the space would eventually become one massive bank.

CHAPTER IX.

DELTA SYSTEMS AND RESERVOIRS.

1. **Delta rivers.**—The following extracts from a description* of Delta rivers given by Col Rundall, C.S.I., R.E., explain the peculiarities of works constructed on this system.—

The term "Delta" is usually understood to comprise that portion of land which is situated between two of the main branches, and which is shaped like the Greek letter from which it is named But the term is more properly applicable to all land which has been formed by the inundation of a river from that point in its course in which it overflows its natural banks The three great Delta rivers in Madras, the Cauvery, Kistna and Godavery, all have their sources in the Western Ghats After leaving the mountains the Cauvery flows through hilly country until it reaches the plains within 100 miles of the sea, but the Kistna and the Godavery, after traversing the greater part of the Peninsula, encounter the range of mountains which skirt the Eastern coast upward from the latitude of the Kistna, and break through them within 50 miles from the coast. The Mahanaddy, in Orissa, has its source in the plateau of Central India, and also bursts through the Eastern Ghats at about 60 miles from the sea.

In all these rivers there are indications of the sea having formerly washed the base of the hills, so that the alluvial formation has been a process of gradual reclamation, a process which is still going on, and must continue as long as these rivers carry away the enormous amount of detritus with which their freshes are charged. As soon, then, as a river bursts through from the high ground into the ocean, it deposits the matter which it has held in suspension, and gradually makes land until the new formation rises above the surface (*Plate* XXIX, *Figs* 1 and 2). The river then flows over this newly-formed ground and of course, as the largest amount of deposit always takes place where its velocity is first lost, the ground in the immediate vicinity of the river gradually rises and forms its banks. Succeeding freshes wear a shallow trough for themselves through this ground, but as they always rise above the level of the banks the latter also begin to rise higher and higher at the margin, until at last they are only occasionally overtopped in floods, and so the silt is carried further and further—always in the same manner—making fresh land, spreading out in a fan like shape. In process of time, as he direct course to the sea becomes longer, and the trough of the river becomes more defined, the overflow in successive freshes naturally follows the direction of the greatest slope, which is more or less perpendicular to the river banks, and this overflow cuts by degrees new courses for itself—generally by the shortest route to the sea. The new channels, thus made, in time become new branches of the river, and it is generally found that the branches of a Delta river multiply as it approaches the sea

After a Delta has been formed, the slope of the river bed will be found greatest at the point where it first breaks from the mountains or high ground, and to gradually diminish until it reaches the sea level It may easily be understood from this, that, as a Delta

* Vide Lectures to School of Military Engineering, Chatham, 1876

extends, and the course of the river to the sea gets longer and longer, the declivity, both of the bed and surface, must gradually become gentler, until it is no more than a few inches in the mile.

When the slope thus gets diminished, the river, in order to discharge the volume with which it is charged, *must* alter its other dimensions, and therefore increase either in width or depth—generally in both. It is then that changes it its regimen commence, the banks erode, the depth increases, and general irregularity of section prevails. As new branches get formed a large portion of the volume is abstracted into the new channels, and the original main course becomes choked with sand and deposit.

Sometimes the relative size of the main river and its branches get so completely altered, and the regimen so disturbed, that it is a difficult and a very expensive matter to re-regulate properly their relative discharges during floods. While such rivers are allowed to take their own course unrestrained, all sorts of complications arise with the riparian landlords, and in the attempts to benefit the community a good deal of individual hardship must necessarily occur, but still the interest of the few must give way to the safety of many.

2. **Peculiarities in some Delta rivers.**—There is one characteristic in Delta rivers which requires to be specially dwelt upon. Though it is not noticeable in every main river, yet it is one which will be found in some of the branches of almost every river, and that is, a gradual diminution in sectional area and of discharging capacity. This occurs most noticeably in the case of the Mahanaddy, in Orissa, where the sectional area of most of the branches at a point 25 miles lower down is little more than half what it is at the head of the Delta. What has led to this condition is not capable of exact explanation, but it is a fact which has rendered it difficult to determine on the best mode of dealing with its extraordinary floods. Like all Delta rivers the Mahanaddy overflows its banks in extreme floods to a greater or less depth at various points of its course. To prevent the low land from being injuriously flooded, marginal embankments are necessary, and have been constructed over the greater portion, but as they were constructed at intervals, and without special reference to the river's discharging capacity. the result has been that at times of extraordinary floods the embankments give way in many places, and great loss ensues in the localities inundated.

Another peculiarity in Delta rivers is that the declivity of the bed is not, as one might suppose, distributed regularly, but is divided into series of steep and flat slopes. The inclination of the surface of the water in floods does not follow that of the bed exactly, but nevertheless. it also is not exactly uniform, but the slopes of the banks is more regular, gradually diminishing from the head of the Delta to the sea.
The consequences of embanking the upper reaches, and so preventing any spill over the banks, is to throw a much larger volume into the lower reaches, and raise the level of the river's surface. This is a point which it is requisite to bear in mind when protecting projective embankments on a Delta river.

There is also a curious phenomenon connected with the river wave and the velocity with which it travels. This velocity is quite distinct from the current. It is merely the speed at which a sudden accession of a fresh volume of water into the river travels.

In the Godavery the wave travels about 2 miles per hour, while the surface velocity of the current, in full flood, is between 5 and 6 miles per hour. The explanation of this phenomenon is clearly described in Messrs. Humphrey and Abbott's book on the Mississippi. It is a point requiring to be studied, for on it depends the calculations of

discharge, as on the period of the passage of the wave at the point selected for observations of the river's rise and fall depends the local flood slope As long as the river is rising the *top* of the wave has not yet arrived, and the slope, and hence the discharge, at any given stage of the river, will have its maximum value for that oscillation When the river reaches its highest point the *top* of the wave is passing and the slope being less than before, the discharge must diminish When the river is falling the *rear* of the wave is passing, and the slope, and hence the discharge at any given stage, will have its minimum value for that oscillation

3. **Characteristics of Delta river**—The characteristics of a Delta river may thus be summed up —

I.—In high floods it rises more or less above its natural banks

II —Its declivity is continually decreasing as it approaches the sea or (if it be only a tributary) the point of its junction with the main river

III.—The slope of the flood surface though it does not follow exactly that of the bed yet similarly decreases

IV —Its sectional area, in some instances, diminishes at a certain distance from the head of the Delta

V —Its bed runs on a higher level than the country, at greater or less distances, in a direction perpendicular to its course

Hence a Delta river, while particularly adapted for irrigation, can never be used for carrying off surface drainage, which must be disposed of by separate channels of its own

4 **Configuration of a Delta.**—Having explained the peculiarities of the river I will now proceed to describe the configuration of a Delta itself (*Plate* XXIX *Fig* 2) To the eye of a casual observer it presents one uniform dead level, but it is by no means so in reality, on the contrary, it is broken up into distinct gentle undulations whose direction will generally be found to follow the course which the spill of the floods has taken

The Delta thus consists of a series of ridges and hollows of greater or less width a apart, ordinarily lying in a direction more or less oblique to that of the river itself In some instances ridges are met with which have evidently been beaches left by the receding ocean, their direction being more or less parallel with the *coast* line This configuration in Deltas greatly facilitates irrigation operations for, as will at once be seen, if the irrigating channel be carried along the ridges water can be led from it on either side until it reaches the hollows, which then can be made to serve the purpose of drains and carry off the surplus water to any convenient lower level or to the sea itself

5 **Four main operations connected with a Delta project.**—There are four main operations connected with a Delta project, *viz* —

I —Protection from inundation

II —Irrigation

III —Drainage

IV —Navigation

6 **Protection from Inundation**—The necessity of the first operation will be apparent from what has already been said as to the inundating property of Delta rivers

As a general rule it will be found expedient if not absolutely necessary, to restrict the floods to the course of the rivers by marginal embankments, for while they are very fertilizing to the lands bordering the river margin over which they flow sluggishly and with no great depth, depositing a considerable amount of valuable alluvium, yet, as they flow on to the lower lands, their volume and velocity increase and as they can only pass off very slowly, the low lands become submerged for long periods together without any

compensating benefit from alluvial manure, and so any crops which may be standing thereon are utterly destroyed, and the land rendered unfit for cultivation for the rest of the season. The first thing to be done, then, in investigating a project, is to ascertain the extent to which the river and its various branches are subject to inundating floods and, next, the practicability of restraining them.

For this purpose all the statistical information available, relative to the particular river in question, must be carefully examined; the periodicity, height, duration, and number of floods annually must be carefully noted. The maximum discharge in ordinary, high, and extraordinary floods, should be observed at various points along the river's course, both above and below, as well as at the Delta head. The longitudinal slope of the bed and flood surface, the sectional area, and the longitudinal as well as transverse declivity of the country must be carefully taken. From these the relative capacities of discharge of all the branches of the river should be carefully calculated and compared with the total discharge in the undivided stream, and on their result must depend the measures to be taken as to the disposal of excessive floods. If these should show that the regimen of the several branches is generally uniform, then the process of embanking may be safely pursued, but if, on the other hand, it is found that the capacities of the various branches have become deranged, that any one or more branches have been so enlarged as to carry off more than the proper proportion of the floods, then it will be necessary, first, to adopt measures to restore the equilibrium of the various branches, and then to proceed cautiously and systematically with the process of marginal embankments. Cautiously, *for it must be borne in mind that when the spill of a river in the upper part of its course is shut off and the volume thus arrested is thrown into the lower reaches, the surface level* will be considerably raised there, and, unless precautions are taken the adjacent country will become deeply swamped, and much damage ensue.

Simultaneously with the construction of embankments the regimen of the river must be strictly maintained, and its course regulated by protecting its banks, wherever necessary, from violent sets and eddies. In Northern India the soil of both bed and banks is very friable and, consequently, when a river begins to erode, the process of destruction goes on very rapidly, and as much as a mile of the natural bank will be eaten away in a very few days

In Southern India the banks consist of stronger clay, therefore erosion is slower, but yet, in certain points the banks, even there, crumble away very quickly. In the Delta of Tanjore the river banks are systematically protected by groynes composed of palmyra trees and matting, stone being so distant that it would be too expensive to use it. On the Kistna, Godavery, and Mahanaddy, stone is cheaper and, therefore, is largely used for such work.

The dimensions of river embankments depend, of course, on the quality of the soil available for their construction. In height, that is, when consolidated, they are usually made three feet above the highest known flood. Ordinary earth when loosely thrown up and unstamped usually sinks two inches in a foot, allowance must therefore be made to meet this sinkage when putting up the profile for any new embankment. The slopes, also, must depend on the quality of the clay. The river slope is generally made at two to one and the land slope at one-and-a half to one, but in light soils it is necessary to increase these proportions. Where turf can be had at a reasonable rate it is good economy to lay a layer of it over the slope, as the banks are then protected from guttering. The width of crest depends on the height of the bank, but as the river bank usually serves the purpose of a footway for passengers and pack cattle, the crest is made 8 or 9 feet wide.

If there happens to be no artificial irrigating channel running parallel to the embankment, then it is necessary to build sluices at intervals to admit the floods on to those lands which before benefited by the alluvium carried by the spill. It will sometimes be found desirable to plant the river face of embankments with long grass or with the palm or any other tree whose roots tend to bind the soil firmly together In such localities as are exposed to the action of waves, raised by the prevailing wind a protection of some kind will be found necessary, but it occasionally happens that a heavy storm or cyclone occurs when the river is in full flood, and then the bank slopes on the lee side of the river must suffer from the lash of very heavy waves, against which it is scarcely practicable to provide any permanent protection at any reasonable cost

7 **Irrigation.**—As before observed, the peculiar configuration of a Delta renders the delivery of water from the river an easy matter From the fact of Delta rivers running on a high level, their beds will be found to be on a level with the adjacent country, at no great distance, in a direction at right angles to their course Hence, with the exception of a small triangular slip near the head of the Delta the whole tract is commanded by the river, land its water can, therefore, be conveyed to any part of it

As during the low state of the river there is but a small depth of water and the banks at the Delta head are high, it would necessitate both deep cutting and a very wide channel to convey the quantity of water required Hence it is more economical as well as indispensable for navigation purposes to construct a weir across the river for the purpose of raising the water so as to secure the requisite depth for navigation, and at the same time diminish the sectional area of the cutting If the river at the dam site be quite clear of islands, as in the Sone, then the weir is built in one continuous length, otherwise it is constructed in lengths with the flanks abutting on the several islands For instance the weir on the Sone is 2½ miles of clear unbroken masonry On the other hand, that on the Godavery, though aggregating the same length, consists of four distinct portions

Canals are taken off each flank, the main line running to that point, more or less distant, where it is convenient to throw off the principal branches From these branches again the minor channels bifurcate, and they, in their turn, throw off the several distributaries from which the field water courses are supplied

The arrangement generally practicable in a Delta is first to run from either bank a main canal as straight as possible to the point where the surface of the water will quickest reach the ground, from that point a branch is first thrown off towards the river bank and carried parallel with it, if not to the river's mouth, at all events, in Deltas situated on the cast, to as far as the limit of tidal water with which a navigable connection should always be made One or more branches are next led off from the same point according as there may be high ridges of land of sufficient extent or importance to command, while the main line itself is carried on, skirting the edge of the Delta until it also terminates in tide water or in the river with which the Delta may be connected

In laying-out canals in a Delta much the same procedure has to be adopted as has been mentioned in the preceding Chapters for canals generally There is, however, this difference, that the length of main line which has to carry the volume of water required by the land commanded by it is much less as the surface of the country is reached more quickly

compensating benefit from alluvial manure, and so any crops which may be standing thereon are utterly destroyed, and the land rendered unfit for cultivation for the rest of the season. The first thing to be done, then, in investigating a project, is to ascertain the extent to which the river and its various branches are subject to inundating floods and, next, the practicability of restraining them.

For this purpose all the statistical information available, relative to the particular river in question, must be carefully examined; the periodicity, height, duration, and number of floods annually must be carefully noted. The maximum discharge in ordinary, high, and extraordinary floods, should be observed at various points along the river's course, both above and below, as well as at the Delta head. The longitudinal slope of the bed and flood surface, the sectional area, and the longitudinal as well as transverse declivity of the country must be carefully taken. From these the relative capacities of discharge of all the branches of the river should be carefully calculated and compared with the total discharge in the undivided stream, and on their result must depend the measures to be taken as to the disposal of excessive floods. If these should show that the regimen of the several branches is generally uniform, then the process of embanking may be safely pursued, but if, on the other hand, it is found that the capacities of the various branches have become deranged, that any one or more branches have been so enlarged as to carry off more than the proper proportion of the floods, then it will be necessary, first, to adopt measures to restore the equilibrium of the various branches, and then to proceed cautiously and systematically with the process of marginal embankments. Cautiously, for it must be borne in mind that when the spill of a river in the upper part of its course is shut off and the volume thus arrested is thrown into the lower reaches, the surface level will be considerably raised there, and, unless precautions are taken the adjacent country will become deeply swamped, and much damage ensue.

Simultaneously with the construction of embankments the regimen of the river must be strictly maintained, and its course regulated by protecting its banks, wherever necessary, from violent sets and eddies. In Northern India the soil of both bed and banks is very friable and, consequently, when a river begins to erode, the process of destruction goes on very rapidly, and as much as a mile of the natural bank will be eaten away in a very few days

In Southern India the banks consist of stronger clay, therefore erosion is slower, but yet, in certain points the banks, even there, crumble away very quickly. In the Delta of Tanjore the river banks are systematically protected by groynes composed of palmyra trees and matting, stone being so distant that it would be too expensive to use it. On the Kistna, Godavery, and Mahanaddy, stone is cheaper and, therefore, is largely used for such work.

The dimensions of river embankments depend, of course, on the quality of the soil available for their construction. In height, that is, when consolidated, they are usually made three feet above the highest known flood. Ordinary earth when loosely thrown up and unstamped usually sinks two inches in a foot, allowance must therefore be made to meet this sinkage when putting up the profile for any new embankment. The slopes, also, must depend on the quality of the clay. The river slope is generally made at two to one and the land slope at one-and-a half to one, but in light soils it is necessary to increase these proportions. Where turf can be had at a reasonable rate it is good economy to lay a layer of it over the slope, as the banks are then protected from guttering. The width of crest depends on the height of the bank, but as the river bank usually serves the purpose of a footway for passengers and pack cattle, the crest is made 8 or 9 feet wide.

Great portions of some channels have been formed by throwing up one bank only on the lower side of a slope, and the heads of some river channels, by separating part of the bed of the main stream by means of an artificial bank, protected by river grasses, etc In some cases, these artificial banks are carried for very considerable distances up the rivers, or obliquely across their sandy beds Such banks, termed *corumboo*, are generally over-topped and carried away by all freshets of more than 1½ yards depth of water They are temporary expedients or substitutes for permanent dams or *anicuts*, to turn the early and low freshets of rivers into irrigating or tank channels, and being liable to be partially, and sometimes entirely, destroyed by every full fresh, require to be repeatedly repaired and occasionally reconstructed during every season. They are usually constructed and kept in repair by the proprietors of the lands which they irrigate, without any cost to Government.

11 The Currency Works.—These are the upper and lower *anicuts* across the Coleroon, built at the suggestion, and under the superintendence of the late Major-General Sir Arthur Cotton, of the Madras Engineers Both these works have superseded and rendered unnecessary the construction of extensive *corumboos*; while, unlike *corumboos*, they resist the action of freshets, and assist the irrigation in all states of the river The upper *anicut* is built where the Agunda (or whole) Cauvery divides into two branches. the Coleroon, which seeks the sea, by a straight course, falling at the rate from 2 to 3 feet per mile, the smaller but more useful branch (which retains the name of Cauvery) flowing on a more levated bed, and, after having in the short distance of 40 miles, gained no less than 15 feet on the level of the bed of the main branch, dividing and sub-dividing until its water is spread over the greater part of the *Tanjore* district For many years previous to 1836 the Tanjore cultivation had pressed so closely upon the supply of water afforded by the Cauvery, that in seasons falling at all below the average, extensive tracts of valuable land either remained uncultivated, or were subject to the still greater evil of being cultivated in vain *The defect* was chiefly attributed to the accumulation of sand in the upper part *of the stream near* its separation from the Coleroon and to remove which, various expedients *were devised* and adopted with partial but only temporary success.

At this conjuncture, *viz*, in 1834, the late Major General Sir Arthur Cotton, then Civil Engineer of the Division, *devised the anicut* which is built across the Coleroon, about 100 yards below the separation of the *two rivers, and by* raising the bed of the Coleroon about 6 feet, has, without diminishing *except* in a trifling degree, the capacity of its section for the passage of high freshets, *rendered available for* the supply of the Cauvery and of Tanjore, all the water which, even in the driest season, and when most wanted for irrigation, used to *pass* waste to the sea The lower *anicut* was built in the same year, about 70 miles down *the same river*, and serves to turn the water that accumulates in the intervening *part of the river* bed from the drainage of cultivation and the springs that ooze from the sand into the country on both sides, *irrigating* extensive and fertile *tracts of* land in the Tanjore and South Arcot districts, between the *anicut* and the sea

Irrigation Tanks.

12. Tanks. The following extracts from the Third Edition of the Roorkee Treatise on Civil Engineering, give a general idea of this important system of irrigation —

A Tank for irrigation is formed by an embankment thrown across a line of

Drainage, so as to collect the water on the upper side, which is then drawn off for Irrigation purposes by means of sluices and channels.

Tanks are of several kinds. *1st.* Where a '*bund*' or weir is thrown across the gorge of a mountain pass which is the bed of a torrent, thus forming a lake enclosed by the rocky sides of the pass.

2nd. Where a natural hollow in the ground outside the hills is made into an artificial lake by closing up all places where the water can make its exit; such a hollow may be a very small, or may be a large natural basin, drained by a stream or *nala*; and the supply for such tanks may depend entirely on local rain, or on streams swollen by rain in the hills above. There may be a series of such tanks in the same chain or valley or as is often the case, a tank may be filled by a cut from a neighbouring stream, not running through it.

3rd. Where artificial side walls are required as well as the front wall, to enclose the water—in consequence of there being no natural hollow, but merely a continuous slope of the ground in one direction.

It is evident, however, that those three kinds are merely modifications of each other, depending on similar principles for their construction, and that they may be treated of collectively.

13. **Site of Bund.**—In designing a tank, when the source of supply has once been ascertained, the first point to be determined is the position of the *bund* by which the tank will be formed. Other things being equal, it is evident that the narrowest part of the gorge or hollow should be chosen so that the length of the embankment may be as short as possible—and in most cases this will be found to be the best site. But it is also to be looked to that this *bund* shall hold up the greatest quantity of water possible, and this may in some cases modify the actual site of the embankment. It is evident that the amount of water so held up will depend on the area covered by the water and its depth. This depth again will depend on the height of the embankment and the slope of the bed of the tank—for the water can nowhere rise higher than the lowest part of the top of the embankment (natural or artificial) which dams it up, but will then, if the supply be continuous, escape at that point. Sometimes, therefore, it will be found that a *bund* at some other spot than the narrowest, may give a larger area or greater depth above so as to hold up such an additional quantity of water as will amply repay the cost of the increased length of the *bund*.

Other points to be taken into consideration in selecting a site for an embankment are, the relative level and position of land to be irrigated, the quality of soil for foundations, and the proximity of stone and lime, fuel and water, for the supply of the works when in progress.

Briefly, the indications most favourable to the construction of a tank embankment may be thus enumerated:—*1st*, A channel bringing down an ample supply of water; *2nd*, For the bed of the tank, a broad expanse of nearly level land in front of the embankment, having a slight dip towards the latter; *3rd*, That the land to the rear be of greater extent than the bed, and slightly lower in its level, in order that every portion of it may be irrigated through masonry sluices constructed in the embankment, and communicating with earthen channels leading to the field; *4th*, A rock foundation at little depth from the surface; *5th*, That during the dry season water be procurable from the bed of the water-course, or from a well, for the use of the work and work-people; *6th*, That stone, lime, and fuel be within reasonable distance; *7th*, That the soil of the tank area is of a retentive nature.

It will rarely happen that all these advantages are offered at one locality. The main object of the tank, it is to be recollected, is the irrigation of the land below it A careful survey of the proposed site should be made, including the levels of the intended dam, and of the land to its front and rear. The elevation of the embankment, and the area of the bed to be submerged, may then be adjusted and determined, and an opinion as to the irrigation powers of the tank, in reference to its depth and expense may be formed. The expense of the work is then to be contrasted with the probable return from the irrigation of the land commanded, from the growth of luxuriant crops in the bed after the withdrawal of the water, and from the more indirect benefit arising from the multiplication of wells supplied by filtration from the tank

Irrigation by tanks is often combined with that by rivers, the water from the rivers being brought into tanks that are favourably situated, by means of channels cut through the river bank and intervening ground

14. Waste weir —It next becomes necessary to determine in what way the surplus water that may be thrown into the tank shall escape If there is perfect control over the stream by which the tank is fed, the water may be turned off when the latter is full, by means of a sluice at the head This, however, will not often be practicable, and in any case, an escape must be provided from the tank itself for the surplus water. This may be allowed an exit in two ways, either over the whole or a part of the dam itself, or by a side channel (as at C *Plate* XXX), arranged so that the surplus water shall flow down it as soon as it comes nearly on a level with the top of the embankment If such a channel can be provided at a moderate expense, it is always the preferable method as there is then no danger to the dam from the shock of water falling over it—nor of silt or boulders accumulating in the tank, nor of the irrigation channels and sluices being injured

But in many cases, especially where the tank is formed inside the hills, the expense of cutting such a side channel would be too great, and the only passage for the side water must be by the dam itself To effect this, flood gates must either be provided, or the water must pass over the whole or part of the dam In peculiar cases, the former method may be allowed, but as a general rule, the latter method is preferable, as being self acting If the dam is of no great length, and can be made of solid masonry throughout, then the whole of it can be arranged as an overfall If so large an escape is not required, and the embankment is of earth for the greater portion of its length then a portion of the dam must be built of masonry, (the top being 3 to 5 feet* lower than that of the earthen embankment), and will serve as an overfall or waste weir

15. Form and Material of Dam The thickness of the embankment must of course depend on the nature of the material as well as on its height and the violence of the stream that has to be arrested In damming up a small hill torrent, boulders will generally be found in sufficient quantity to yield abundance of lime and stone, and if fuel is cheap and water at hand, it may be possible to make the whole dam of boulder masonry. If not, then the portion forming the overfall must at any rate be so constructed, and the remainder may be made of dry boulders with a long slope on each side, and a masonry wall in the centre to prevent leakage The thickness should of course decrease from the bottom to the top, and that portion over which the water is to pass, especially if it is to be of any great height, should be raised, little by little, in successive seasons, the water being allowed to flow over it freely It will thus have time to consolidate and its strength be satisfactorily tested. The foundations should be carried down to rock if

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* Where wave action is likely the top of dam may have to be a considerable height above maximum water level.

possible—or at least to firm soil. If this is not found at a moderate depth, an artificial foundation of concrete or rubble masonry must be formed. The superstructure should be carried into the side rocks to prevent their being turned.

Where the supplying water is less violent, and in the case of tanks outside the hills, such precaution and solidity of workmanship are of course not requisite Boulders too will be scarce, or perhaps wanting altogether,—so that earth or brickwork will have to be the material employed. The earthen embankment must of course be made very massive, and if it can be protected from the action of the water by a layer of masonry, dry stone, or puddle, it will be advantageous. If not, it should be well turfed or defended with piling and wattling. Of course no part of the earthen embankment can be used as an overfall, and if there is no separate escape for the surplus water, a portion of the embankment itself must be made of masonry to act as an overfall. No earthen dam can be relied upon when the structure is of very great heights, exceeding say 70 feet.

16. **Earthen Dams.**—The ordinary mode of construction adopted in England for works of this class, may be explained generally in very few words. With a breadth of from 20 to 30 feet at the top, the dam slopes towards the water with an inclination of 3 feet in length to 1 of height, and in the opposite direction, with an inclination of 2½ feet to 1. Along the middle of the dam and carried down (as it should be, though as it often is not) to a firm impermeable bed, is a wall of clay technically called *puddle*. This wall is usually about 10 or 12 feet wide at the top, and thickens as it descends at the rate of about 2 or 3 inches for every foot of vertical distance. On either side of the puddle is placed what is termed 'selected material,' that is, generally, the best that can be got at the spot. The rest of the dam is formed of almost any kind of suitable earth. In order to break the force of the waves, and to prevent them from washing away the earth underneath, the slope towards the water is usually covered with a layer of stones, or *pitched*, as it is termed. The outer slope is turfed or pitched, according to the judgment of the Engineer.

It is the puddle wall which should form the barrier to the escape of the water, and it is this part of the embankment to which the Engineer trusts more than to any other for the safety of his works. The greatest care should be taken both in the selection of the clay, and in the manner of putting it in the embankment. It should be thrown down in thin *concave* layers, as should also the rest of the dam, and should be with the rest well watered, and rammed and beaten, and trodden down so that the whole mass may be rendered as homogeneous as possible.

Great pains should be taken to ascertain that the ground composing the bed of the proposed reservoir is such as will hold water without the enormous expense of puddling the whole or part of the bed

There are very many cases where, owing to the formation of the ground, the presence of particular strata in the formation will render the construction of the works dangerous, if not useless. The danger consists in this, that the water may find its way underneath the puddle trench and weaken the backing of the puddle, or the puddle itself, whilst leakage through hard rocky strata, although not of much importance at ordinary times. might yet be such as would cause a want of water in severe droughts, when water is most equired. In order to meet this difficulty, it has been necessary in some cases to sink trenches to a depth of 80 or 100 feet below the bottom of the dam and fill them with concrete, and thus intercept the leakage through the ground.

If in the trial holes it should be found that the strata are intersected by fissures, or are dislocated or disturbed, it will either be necessary to abandon the site, or excavate underneath the dam a trench which will require to be filled with clay puddle or concrete, and this watertight trench will have to be carried to such a depth as will effectually intercept such sources of leakage, and should be taken right through the disturbed ground into the solid beneath, and be also extended for a sufficient length into the natural ground at the ends of the dam If the puddle trench is in rock, which is intersected with fissures it is well to line the back of the trench with 1 foot 6 inches or 2 feet of cement concrete, so as to prevent the percolation of water reaching the back of the puddle trench and weakening it (*Plate* XXXI)

17 **Masonry Dams**—In France and Spain, the countries in which we find so many large reservoirs, the people put no faith in puddle and earth, except for dams of moderate height They trust to masonry and certainly they have no reason to complain of misplaced confidence

Some of the dams in the latter country have stood for hundreds of years, are in use to day, and although constructed at a period when science was but emerging into light, and when therefore, no great knowledge of the theory of the subject could be expected, yet from their having been built of masonry, still answer all the purposes of the original designers

The Spanish dams are of huge proportions, and having been built according to no generally accepted rules, there is very little similarity between even any two of them It would, therefore, be impossible to give any description of them which should apply to all

Rude though as these works seem to us by the light of modern science, it is a great point that they still exist, and still fulfil their object In other words, they have been successful in spite of the errors made in constructing them It is not likely that these errors will be repeated

The construction of masonry dams is a large and important subject in itself and beyond the scope of this Manual Those particularly interested should consult the many special treatises published on this class of engineering

18 **Sluices of Irrigation**—Each tank is provided with from one to two, and some times three, sluices, by which the water can be let out to the fields at pleasure Their position is generally on a level with that of the bed of the tank, but if any portion of the lands to be irrigated be above that level, one or more of the sluices is placed at a corresponding height

Until lately it was a common practice to lay the outlet or supply pipe through or under the embankment, and, in some cases, even without preparing a special foundation for it The great loss of life and destruction of property caused by the bursting of reservoirs has, however, effectually put a stop to this system, and arrangements are now generally made by which the outlet works are altogether disconnected from the dams We have in fact learnt by disaster, what common sense should have taught us from the first The dam being naturally the weakest part of the reservoir, should be that which we could least afford to endanger by works liable in the course of nature to get out of order The practice now obtains of carrying the outlet pipe through some one of the hills standing on the margin of the tank.

19 **Madras Tanks**- The banks of the majority of tanks in Madras seldom exceed 15 feet in height Some of them are, however, 40 or 50 feet high and even more, many of them are formed of earth only, in a few instances carefully turfed, while the

larger works, and in places where stone is abundant, many of the smaller banks also, are protected by loose blocks of rough stone laid on the inner sloping surface, or disposed in the form of a nearly-upright revetment, without mortar or cement. The object of these rough stone facings is not so much to support the earth-work, as to protect it from the action of the waves during stormy weather, and from damage by the monsoon rains

Many tanks are often formed in the same valley, the bed of one beginning where the cultivation under that above it ceases. In consequence of this, the breaching of one tank often leads, by the sudden influx of its waters, to the bursting in succession of those below it. This is more particularly the case when heavy and sudden rains succeed seasons of drought, during which the earth of which the tank banks are composed loses its tenacity, and is soon saturated by water. Another, and the general cause of the breaching of tanks, is the neglected state of their banks, which are not in all parts sufficiently raised above the surface of the water in them. High winds exciting waves in the tank, throw the spray over the lowest parts of the banks, which are thus gradually worn away, until at last the water overtops them, and a breach ensues.

There are also large numbers of valuable irrigating tanks in Mysore, Ajmere, Mhairwara, and other parts of India.

20. Dimensions of Tanks.—In designing a system of tank irrigation it is of importance to make the depth and capacity of the tank sufficient to make the *net* storage really useful for irrigation. The losses from percolation can often be usefully recovered by irrigating from wells in the vicinity, and this in itself will, in many cases, richly compensate for the expense of the construction of a tank; but it must be borne in mind that the evaporation from a shallow tank may become a very serious item of loss, and indeed in extreme cases, deprive the work of any real useful effect. A small deep tank will, therefore, probably give a larger net discharge than a larger but shallow work and be more really useful, except in so far as the advantage which may be gained by cultivating the bed of the shallow tank after the surface water has been removed. In general, tanks with depths less than 10 feet cannot be considered permanent sources of irrigation.

21. Chains of Tanks.—The chain system of tanks, common in Mysore, consisting of a series of tanks laid out one below the other along the course of the valley of a stream, forms a very valuable style of storage, but is subject to great danger when the works for the rapid and complete removal of the surplus supplies or insufficient or weak. It is evident that the breach of any one tank in the series will almost certainly involve the destruction of all the others below it, and it is, therefore, necessary to design the waste weirs of a chain system of capacity sufficient for even the most violent floods.

22. Capacity of Tanks.—An irrigation tank to be a thoroughly sound and economical work, should hold just the volume required (after deduction of losses) to irrigate the area commanded for irrigation. In practice

however, the capacity is generally determined by the height of bank economically possible, or by the supply of water available, and both of these dimensions will vary with every locality

The calculations of discharge off catchment areas require special care in the case of tanks both for maximum and average volumes—the engineering dimensions of the works depend on the maximum, and the useful irrigating effect on the average, volume

The most reliable formula in use in each locality should be employed for calculation In Madras the formula used is $Q = C M^{\frac{3}{4}}$, where $Q =$ maximum volume in cusecs, $M =$ drainage area in square miles, and C is a co-efficient depending on the nature of the country, and varying from 200 to 300 for sandy level country to 700 for hill tracts When a portion of the catchment area of a tank is occupied by other tanks, this formula is modified on the assumption that these other tanks are regulating or modifying the discharge *

In this case $Q = C M^{\frac{3}{4}} - \frac{c}{5} m^{\frac{3}{4}}$

Here $M =$ the whole drainage area and m the portion of it occupied by another tank or tanks

23 **Extension of Tank system**—The extension of the tank system of storage for India is a most important agricultural question, and one which will repay the most careful investigation In Egypt the loss which would otherwise result from low Niles is compensated for by a system of storage in a most satisfactory manner, and there is reason to believe that similar protective works might also be carried out in India

* Mr Davidson.

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Fig. 41.

Scale—10 Feet = 1 Inch

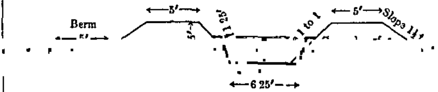


Fig. 43.

SKETCH SHOWING ARRANGEMENT OF
SIDE AND CROSS DRAINS

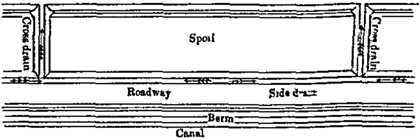
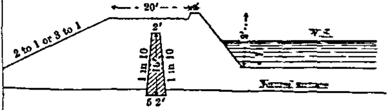
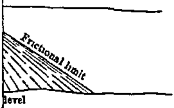


Fig. 45.





STRIBUTARY

0 Feet = 1 Inch

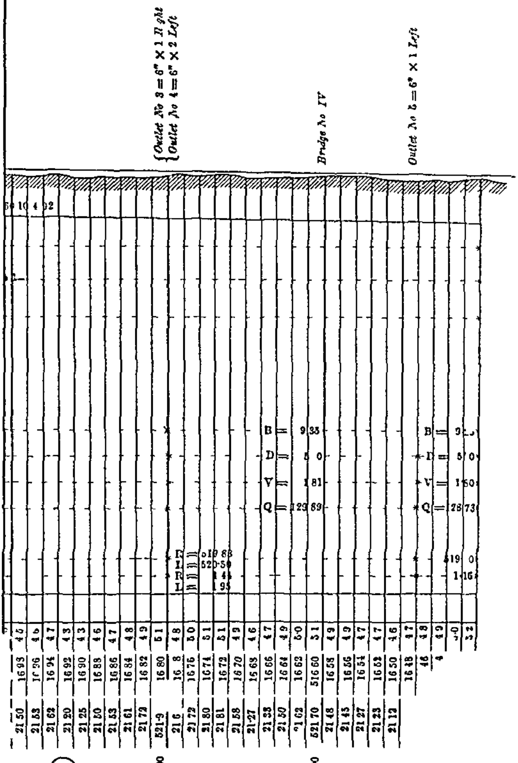


Fig 56

TCH OF CANAL HEAD WITH RIVER LOCK AND
UNDER-SLUICES SHOWING GROYNES

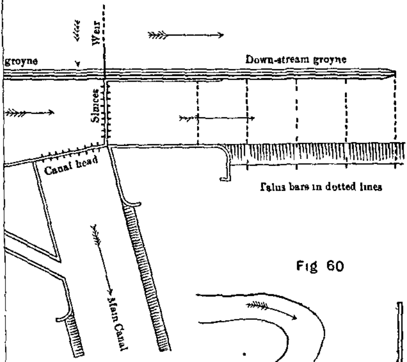
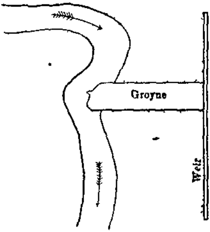


Fig 60



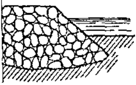
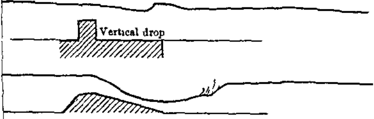


Fig 63



At the Okhla Weir near Delhi wh ch has a sloping outfall, with a flood
40,000 cubic feet passing the crest, velocity was found to be 9·33 and the
veloc ty 18 feet per second

Zinco June 1914—No 7540-10 900